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Fakulteten för landskapsplanering,
trädgårds– och jordbruksvetenskap

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– biological control of thrips in cucumber

Effektiviten hos det nylanserade rovkvalster *Amblydromalus limonicus*

– biologisk kontroll av trips i gurkodling

Erika Skytte af Sätra

Självständigt arbete vid LTJ-fakulteten, SLU

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Abstract

In this study, the efficiency of a newly launched predatory mite, *Amblydromalus limonicus,* has been examined for its potential to use as a biological control agent in cucumber production. *A. limonicus* can be used for biological control of two thrips species, *Frankliniella occidentalis* and *Thrips tabaci.* Field trials were conducted in greenhouses of two conventional cucumber growers in Scania, the southern part of Sweden. The basic control agent used against thrips was the predatory mite *Amblyseius swirskii*. In selected areas, additional *A. limonicus* was released. *A. limonicus* were released twice after the transplantation of the second crop in a dose of 100 predatory mites per square meter, with a two week interval. The thrips population was monitored in three ways during the season; counting of trips caught on blue sticky traps and counting of thrips found in the flowers and on the leafs. The results indicate that the thrips population on plants decreased when both predatory mites, *A. swirskii* and *A. limonicus,* were released. The overall low thrips infestation may have contributed to a negative interaction between *A. swirskii* and *A. limonicus*, due to cannibalistic behavior. Following the second release of *A. limonicus,* a lower total density of predatory mites were found. The area treated with only *A. swirskii* had a higher total predatory mite density which indicates that *A. swirskii* is efficient at this level of pest infestation. One of the growers leaves the greenhouse empty for two weeks between the two cultures. Following this period the population of *F. occidentalis* decreased to a low level. This raises the question whether this kind of treatment can be useful in an integrated pest management strategy.

Sammanfattning

Målet med denna studie har varit att utvärdera effektiviteten hos ett nylanserat rovkvalster, *Amblydromalus limonicus*, som biologisk kontroll mot trips i konventionell gurkodling. *A. limonicus* användes för biologisk kontroll mot två tripsarter, *Frankliniella occidentalis* och *Thrips tabaci*. Fältförsök har gjorts under säsongen 2012 hos två växthusodlare i Skåne som bedriver konventionell gurkodling. Som basprodukt i bekämpning av trips användes rovkvalstret *Amblyseius swirskii.* Utvalda ytor behandlades även med *A. limonicus*. *A. limonicus* sattes ut i en dos om 100 rovkvalster per kvadratmeter vid två tidpunkter, med två veckors intervall. Tripspopulationen studerades under säsongen genom att räkna antalet trips som fastnat på blå klisterskivor som var placerade i varje växthus samt att räkna antalet trips på blad och i blommor. Resultaten indikerar att tripspopulationen på plantorna minskar när *A.swirskii* sätts ut och att den inte påverkas vidare av *A. limonica*. Efter andra utsättningen av *A. limonicus* hade de områden som enbart var behandlade med *A. swirskii* fler rovkvalster. Den större populationen av rovkvalster antas bero på det överlag låga tripsangreppet vilket kan ha medför en negativ interaktion mellan *A. swirskii* och *A. limonicus,* i form av kannibalism. Sammantaget indikerar resultaten att *A. swirskii* är tillräcklig vid tripsangrepp i denna storlek. Den ena odlaren tömmer sitt växthus under två veckor mellan de två odlingskulturerna. Efter denna period minskade tripspopulationen drastiskt. Det är därför intressant att ställa frågan huruvida den typen av behandling skulle kunna tillämpas i ett integrerat växtskyddsprogram.

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Erika Skytte af Sätra

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1. Introduction

Biological control of greenhouse pests with parasitoids and predators has been used for a long time. Problems with resistance against insecticides and a new EU-directive based on the ground pillar to use as little chemicals as possible in horticultural production are some of the factors that raise the demand for new biological control agents. The market for biological control agents is constantly expanding, with new organisms becoming available.

In 2014, EU will implement the regulation of Integrated Pest Management (IPM), in order to achieve sustainable use of pesticides. The regulation emphasizes the use of preventative management tools, primarily the use of biological control, target-specific chemicals and good prediction models. Biological control agents are very important tools in a successful IPM strategy.

In Sweden, cucumber is an important crop since it constitutes the largest area of greenhouse cultures. Cucumber production faces many different pest and disease problems. One of the major insect pests is thrips, causing leaf injuries and misshaped or scarred unsellable cucumbers. The Western Flower Thrips, *Frankliniella occidentalis,* has become a world wide pest of many greenhouse crops due to its resistance against many insecticides.

F. occidentalis was first observed in Sweden in 1985 and has since become a problem in many cultures, including cucumber. In Sweden, biological control is widely used and many growers use predatory mites preventatively against different pests. However, products that can be used to create efficient curative thrips control have not been available until recently.

In 2012, a predatory mite named *Amblydromalus limonicus* became commercially available. Its efficiency in controlling thrips and whiteflies has been known for a long time, but mass rearing of the predatory mite has only recently been successful. Studies have showed its efficiency to control high infestations of thrips and whiteflies in greenhouse vegetable crops, including cucumber.

A. limonicus is unique in its predation behavior against trips since it both feeds on first and second instar larvae. Other, currently available, predatory mites only feed on first instar larvae. The breeding system and predation rate of *A. limonicus* is superior to other predatory mites and *A. limonicus* is also active at lower temperatures.

This thesis is part of a participatory action research project conducted within the division of Integrated Plant Protection at the Department of Plant Protection Biology at the Swedish University of Agricultural Sciences, SLU in Alnarp. The research group consists of cucumber growers, both conventional and organic, advisors from the Swedish board of Agriculture and researchers at the university.

This thesis will present field trials performed in two greenhouses with commercially grown cucumber. The efficiency of *A. limonicus* as a thrips control agent has been examined. The study was conducted during the growing season of 2012 *A. limonicus* was released a couple of weeks after transplanting the second cucumber crop, since thrips problems often are most severe during this part of the summer.

1.1 Objectives

The aim of this thesis is to investigate if the new predatory mite *Amblydromalus limonicus* could be used as an efficient biological control agent in an IPM strategy to control infestation of thrips in cucumber production in Sweden. Since it is a new predatory mite for the Swedish market one of the objectives of the study is to obtain experience on how to use the product.

The main questions:

- Will *A. limonicus* contribute to reduced damage from trips and increase the efficiency of biological control in greenhouse produced cucumber?
- How should *A. limonicus* be used and how will it perform in combination with the predatory mite, *Amblyseius swirskii*?
- Can *A. limonicus* be useful in an IPM-strategy in cucumber production in Sweden?

1.2 Limitations

The study took place at two greenhouses situated near Helsingborg in Scania, Sweden. This location is interesting due to the concentration of cucumber producers and ornamental producing companies that hold a certain level of pest pressure, especially of *F. occidentalis,* during the seasons. Both of the growers produce cucumbers by integrated production according to Swedish regulations.

The species of *F. occidentalis* and *T. tabaci* were determined to species level; other trips were recorded as unidentified trips. Thrips larvae were recorded but different larval stages were not separated. In field, the predatory mites (*A. limonicus* and *A. swirskii*) were not determined to species level and thus just recorded as "predatory mites". Five samples of predatory mites have been sent to Koppert BV. in The Netherlands for determination of species. Eggs of predatory mites were not counted in the study.

2. Background

2.1 Implementation of IPM

The term Integrated Pest Management, IPM was stated in US Academy of Science in 1969. By then it was a reaction to what critics thought off as an overreliance on, and miss-use of, chemicals. The concept was based on a combination of biological strategies, favoring natural enemies, and on the aim to spray as little chemicals as possible (Aglearn.net).

In 2009, The European Union developed a directive which contains eight general IPM principles that will be implemented in EU member states in 2014. The guidelines mention preventative work including measures for prevention/suppression of pests, the importance of using monitoring tools and economical threshold values to create a base for decisions for when and how to apply chemicals. Primarily non chemical methods and target specificity chemicals shall be used in order to suppress the resistance pressure. Documentation during seasons will be important in order to evaluate the success (European Commission, 2009; Naturvårdsverket, 2010).

In Sweden, many of these principles are already in use but according to the Swedish Board of Agriculture the implementation measures for preventative actions and knowledge about threshold values needs to be improved (Jordbruksverket, 2012d)

One of the reasons for implementing these kinds of regulations is the increasing complexity of pests and diseases due to the world trade of horticultural crops. Global trade facilitates the spread of insects and other pests. Problems in production, mainly of ornamental crops where tolerance for damage is very low, have forced growers to intensive chemical programs. This in turn has lead to pests and diseases becoming resistant and thus increases the control costs (Albajes et. al. 2000).

2.2 Cucumber production

Cucumber is the largest greenhouse crop in Sweden. The total area of greenhouse cucumber was in 2011 605 671 square meters with a total harvest of 26 802 tons, distributed on 156 companies. Tomato, which is the second largest greenhouse crop in Sweden, occupied, a total area of 349 413 square meters and produced 13 543 tons, in 2011. Since 1987, the greenhouse area with cucumber production has increased, while the area with tomato production has decreased. (Jordbruksverket, 2012b). The county of Scania holds the biggest area of cucumber production seen across the country (Jordbruksverket, 2012b). In 2011, cucumber accounted for the highest production value among vegetables and berries grown in greenhouses (Jordbruksverket, 2012c). Due to the economical importance of cucumber in the Swedish horticultural sector, evaluations of products that can be helpful in pest protection are of constant interest.

2.2.1 Cucumber cultivation

Good cultural practices are important because well managed crops are in general less susceptible to pests and diseases. For labor intensive crops such as cucumber, the risk of spreading pests, e.g. when harvesting, is bigger compared to a less demanding crop. Vegetable crops, such as cucumber or tomatoes, are in general more suitable for IPM strategies than ornamental crops. In ornamental production, the vast diversity of cultivars in combination with a very low tolerance for esthetical damage makes the IPM strategy more complicated (Albajes et. al. 2000; van Lenteren & Woets, 1987).

The ability to control the atmosphere, temperature, humidity and CO_2 is important in order to achieve good production. Cucumbers are often grown from transplants that are raised as seedlings in rock wool cubes about 10 centimeters high. The cubes are transplanted on sterilized substrate in rows directly on the greenhouse floor or on low benches. In conventionally grown cucumber the substrate varies from containers with pumice or perlite to rock wool slabs, see Picture 1 (Robinson & Decker-Walters, 1997)

In Sweden, the cucumber cultivation season spans from mid January to October. Temperature is normally set to 20-22 ^oC during day and dropping two degrees at night. The relative humidity should be around 85%. It is most common to cultivate two crops per season, however three crops per season occurs. Transplanting in Sweden often occurs during June or July. This means that the newly planted cucumber plants are exposed to the warm climate during the first weeks when they are relatively vulnerable and the growers have to pay extra attention to the crop to ensure a good development of the fresh plants. One of the difficulties when transplanting during summer is the pest problem. In general, pests are more active during the summer months due to higher temperature. During the summer period amplified pest populations of e.g. thrips occurs inside the greenhouse capable of infesting the plants at high levels. This, in combination with having

Picture 1. Cucumber in double row planted on rock wool slabs.

young plants recently planted in the houses, often gives an increase of the pest pressure. A high infestation during the warm summer months can be devastating for the developing fruits or leaves. In order to control the pests, the growers use climate control, biological control and chemical control (Jordbruksverket Compendium).

2.3 Thrips

Both adults and larvae of the Western Flower Thrips, *Frankliniella occidentalis,* and the Onion Thrips, *Thrips tabaci,* are polyphagous, meaning that they feed from a broad host plant range and cause damage on plants including vegetables, ornamentals and cereals. Damage is most severe on vegetable crops belonging to *Cucurbitacea* and *Solanaceae*. When infestation is high, thrips also cause severe damage in e.g. peppers, strawberries, cyclamens and chrysanthemums (Albajes et. al. 2000).

In temperatures between 25-30 ^{o}C, thrips females can live up to 30 days and deposit up to 200 eggs. For feeding and egg laying, adults prefer young leaves and flowers. *F. occidentails* prefers to aggregate in flowers while *T. tabaci* prefers the leaves. The life cycle of thrips include the egg stage, two larval stages, prepupa, pupa and adult stages (Malais & Ravensberg, 2003).

Picture 2. Misshaped cucumbers due to damage from thrips.

The female inserts the egg inside the plant tissue. Immediately after hatching the first instar larvae starts to feed on the plant tissue. It pierces the cells and ingests the leaf cell content, leaving injuries of air filled cells that causes silver, discolored and occasionally later necrotic spots. Attacked shoots become deformed or stunted. The wounds caused by the thrips from oviposition and feeding from the small cucumbers produces scars and thus deformation of developing organs e.g. misshaped cucumbers, see Picture 2. Second instar larvae are more active than first instar larvae and feed more, which causes greater damage. After the two larval stages the thrips pupates and falls to the ground or, in some cases, remains on the plant (Albajes et. al. 2000). Population growth depends mainly on temperature but relative humidity - RH and host plant can also affect (Malais & Ravensberg, 2003).

Problems with thrips infestation are often recurrent every season, even if the level of damage may vary from one year to another. Thrips can overwinter inside greenhouses and they pupate in soil or in hiding places on the floor. Without efficient control measures this might lead to an increasing population over the years (Albajes et. al. 2000; Jordbruksverket Compendium). The fact that *F. occidentails* occurs on every continent shows its ability to adapt to new climates (Kirk et. al. 2003;Hisaaki et. al. 2007).

2.3.1 The Western Flower Thrips, *Frankliniella occidentalis*

The western flower thrips, *F. occidentals,* is indigenous to Northern Mexico, Western USA and Western Canada but has become a major worldwide greenhouse pest. It was first recorded in Europe in greenhouses in the Netherlands in 1983 and first discovered in Sweden in 1985. Due to world trade of ornamentals, it also spread to South Africa, Australia and New Zealand (Kirk et. al. 2003).

F. occidentalis is distributed throughout the whole plant but prefers to feed on pollen. Even though modern cucumber cultivars does not have male flower and no pollen is available, they tend to aggregate inside the flowers of cucumbers plants (Albajes et. al., 2000;Jordbruksverket, Compendium).

F. occidentalis may do great harm by damaging developing fruits by feeding and ovipositioning. The fruit damage is causing greater economical damage than leaf injuries since fruits may be downgraded or discarded (Shipp et. al., 2000).

The most important factor when estimating the damage from *F. occidentalis* is the loss of harvest due to misshaped fruits. Decision about the need for control actions against *F. occidentalis* in an IPM strategy should be based on an estimation of damage. Shipp et. al. (2000) suggests that flower counting and monitoring with sticky traps is the best way to estimate the damage.

Studies from Canada have shown the economical injury level of *F. occidentalis,* as calculated from control costs, yield potential and fruit prices, to range from 20-50 adults per sticky trap and day or 3-7,5 adults per flower and day (Shipp et. al., 2000).

A population of *F. occidentalis* consists of both females and males. A female is 1,3- 1,4 mm, males are smaller and lighter in color. The reproduction occurs by facultative parthenogenesis. At 25 ^{o}C it takes approximately 14 days for *F. occidentalis* to complete the life cycle from egg to egg. At 20 ^{o}C the life cycle takes about 20 days (Malais, & Ravensberg, 2003; Nedstam, 2007).

The major reason why *F. occidentalis* has become a huge problem is because it has developed resistance against many chemicals used in traditional control strategies. Due to its very short life cycle, *F. occidentalis* produces many generations per year in greenhouse environment. This, in combination with a need for repeated treatment and limited numbers of insecticides available, has created a high level of selection pressure for resistance (Loughner, et al., 2005; Kirk, 2002).

In the early 1990s, the first insecticide-resistant strain of *F. occidentalis* was found. In 2005, studies have shown resistance against the active substance spinosad, which traditionally has been used in chemical control of thrips. Due to its resistance against insecticides and its ability to do great harm in greenhouse production, *F. occidentalis* is one the most researched thrips species. Efficient alternatives to manage infestations of *F. occidentalis* are needed (Loughner, et al., 2005; Kirk, 2002).

2.3.2 Onion Thrips, *Thrips tabaci*

Onion thrips, *Thrips tabaci,* is the most common thrips in greenhouses in Sweden. Reproduction is generally asexual with unfertilized females producing female progeny. The populations mainly consist of female individuals. Males occur mainly outdoors and are smaller and lighter in color. A fully grown *T. tabaci* is 0,8 – 1,2 mm (Nedstam, 2007; Malais & Ravensberg, 2003).

Damage from *T. tabaci* is not regarded as devastating in cucumber production as damage of *F. occidentalis* because *T. tabaci* mostly aggregates on leaves and only harms fruit at very high infestation. So far no resistance against chemicals has been recorded. *T. tabaci* can be colonizing the whole plant but prefers young leaves and aggregates on the underside of the leaves (Malais & Ravensberg, 2003).

2.3.3 Distinguishing between *Frankliniella occidentalis* and *Thrips tabaci*

The most secure way of distinguishing between species of adult *F. occidentalis* and *T. tabaci* is by using a microscope. *F. occidentalis* has eight antennal segments while *T. tabaci* only has seven. Other characteristics that differ are size (*F. occidentalis* is bigger), body color and presence of certain diagnostic hairs (Malais & Ravensberg, 2003).

2.3.4 Other thrips

During summer, other thrips, e.g. the rose thrips *Thrips fuscipennis,* may occur in cucumber greenhouses. Other thrips that are sometimes spotted are the ones that emerge from cereal fields during harvest. These thrips species are not known to cause any damage of importance in cucumbers (Nedstam, 2007).

2.4 Biological control

The definition of biological control is where living organisms are used to control and reduce pests and pathogens to make it less abundant and damaging than it otherwise would be. Eilenberg et. al. (2001) suggests that the term biological control could be divided into four different strategies, these are as follows.

1. Classical biological control, were the biological control agent, that is used, not native to the same area as the pest it will control is. The aim with this strategy is to create a long-term pest control.
2. Inoculation biological control, were the release of a living organism will multiply and control the pest for a longer period, but not permanently. For example the release of predatory mites inside greenhouses. These mites will not be able to survive to the next season, since the greenhouse is emptied in the end of the growing season.
3. Inundation biological control, where the aim is to create a high rate of control to lessen the economical damage but the natural enemies will not be able to reproduce. The success of control depends therefor only on one generation, not their progeny.
4. Conservation biological control where a modified environment can help natural enemies at sight to establish and outlast, examples could be creating refuges for mating, grow crops that serve as food sources or shelter (Eilenberg et. al., 2001).

In this study the strategy of inoculation biological control was used. Predatory mites will be released and the control will depend on the released generation but also on their progeny. The predatory mites will not survive to next growing season.

The cucumber growers in Sweden struggle with many different pests and diseases. The pest situation often varies depending on the location of greenhouses, technical facilities, cultivation practices and the type of pests and diseases present. Some of the most important pests causing damage in cucumber are spider mites, thrips, aphids, whiteflies and leaf miners (Jordbruksverket, 2012e).

The advantages of using biological control agents are many. The handling will often be easier for the grower, compared to that of chemicals. Since there is no waiting time the harvest can proceed without further delays due to treatment. No harmful substances is posed for the employees, thus they may stay inside the greenhouses during application and direct after. There is also little risk of finding residues in food or in surrounding areas. Furthermore, the ability for the pest to develop resistance is eliminated. The difficulties of using biological control are the sometimes complicated systems, containing many different pests and diseases that must receive special treatment simultaneously. This can make the strategy difficult to manage, generating a need for advice and training (Albajes et. al., 2000; van Lenteren & Woets, 1987).

The use of natural enemies is often based on the strategy to release an high dose of natural enemies to kill the pest meanwhile enabling establishment on the crop. This creates balance between the pests and their natural enemies in a, sometimes quite complicated, food web. Natural enemies can be used either preventatively or curatively, i.e. before the pest is present (visible) or after infestation. Some natural enemies do feed on e.g. pollen when the pest not is available while some of the natural enemies perform best when the pest is present, since they reproduce when food, insects or spider mites, is available. Some of the natural enemies also practice cannibalism if no other food source can be found. Often the use of a couple of different natural enemies for each pest is recommended due to their different behaviors (Albajes et. al., 2000; van Lenteren & Woets, 1987).

Many of the natural enemies can also to some extent be used together with different chemicals. The combination of selective chemicals and the use of living organisms to control pests are often necessary in an IPM strategy. The grower also needs to know about the impact of different chemicals on the natural enemies (Albajes et. al. 2000 & van Lenteren & Woets, 1987).

2.5 Predatory mites

Many of the predatory mites used in biological control of thrips and spider mites are generalist predators meaning that they predate on different pest such as spider mites, thrips and whiteflies, all common pest problems in greenhouse cultures. Often they live on pollen in absence of prey. Unless else is stated, the predatory mites mentioned below are members of the Phytoseiidae family. The predatory mites have five developmental stages including egg, larva, protonymph, deutonymph and adult. The development time depends on temperature, humidity, crop, availability of prey and other food sources. In general, species of predatory mites are found on the underside of leaves, along the mid rib or in protected areas depending on the leaf anatomy. Predatory mites from Phytoseiidae can respond to kairomones emitted by the pray, and due to their long legs they disperse easily by walking long distances in the crop (Zhang, 2003).

2.5.1 Natural enemies used in cucumber production in Sweden

The predatory mite *Amblyseius* (*Neoseiulus*) *cucumeris* is used in biological control of thrips and feeds primarily on first instar larvae. In Sweden, *A. cucumeris* is used preventatively in slow releasing bags where mites exit the sachets during 4 - 6 weeks. *A. cucumeris* also come in bottles with carrying material to be sprinkled on the plants. Bottles can be used preventatively or curatively in infested areas, so called hot-spots. At 20 ^{o}C, the whole life cycle is completed in 11 days (Nedstam, 2007).

The predatory mite *Amblyseius swirskii* feeds on first instar thrips larvae, and unlike *A. cucumeris,* it also feeds on eggs and larvae of whitefly (both *T. vaporariorum* and *B. tabaci*). *A. swirskii* can develop on very low amount of prey and on pollen, thus be introduced preventatively. *A. swirskii* is not susceptible to diapause which makes it suitable for cultures with less hours of light. *A. swirskii* has shown better results than *A. cucumeris* in controlling thrips, mainly *F. occidetalis* (Bolckmans et. al., 2005; Messelink et. al., 2006).

Blockmans et. al. (2005) found *A. swirskii* to be better established in the crop and with a population development superior *A. cucumeris*. It is not possible to distinguish *A. swirskii* from *A. cucumeris* or *A. limonicus* in field (De Rodder, pers. comm.).Before *A. swirskii* was available, mainly *A. cucumeris* and also the anthocorid bugs *Orius spp*. were used to control *F. occidentalis* in greenhouses (Bolckmans et. al. 2005).

Many of the predatory mites including *A. cucumeris* and *A. swirskii* have draught sensitive eggs and a RH of minimum 70 % is necessary for eggs not to dry out (Bolckmans et. al. 2005). In Sweden, *A. swirskii* is used in slow releasing bags where mites exit the sachets during 4 - 6 weeks. As *A. cucumeris, A. swirskii* is also come in bottles with carrying material to be sprinkled on the plants. (Koppert-Biological Systems, Info-sheet).

Hypoaspis miles is a polyphagus predatory mite from the family of Laelapidae that feed on ground-living organisms. *H. miles* may be released on the greenhouse floor or in pots or containers where they crawl into the substrate. *H. miles* is primary used against larvae of sciarid flies, springtails and different flies. However, *it* also feeds on thrips pupae and may be used for this purpose (Zhang, 2003; Nedstam, 2007).

Orius spp. are pholyphagus anthocorid bugs and can be used in many crops to control thrips. *Orius spp*. feed on all stages of thrips and the adult will be distributed all over the greenhouse since the adults can fly. The lifecycle of *Orius ssp*. includes egg, 5 nymphal stages and adult (Nedstam, 2007).

2.5.2 *Amblydromalus limonicus*

The predatory mite, *A. limonicus,* has been known for a long time for its potential as a biological control agent but due to difficulties to develop an economical mass rearing system the product was released to the market only in the end of 2011. *A. limonicus* has been regarded as a generalist predator (McMurtry, 1997) and predates on different pest species and pollen, however it is its efficiency of predating on thrips and whitefly larvae that makes it interesting to use as a biological control agent. Studies have shown the promising features of *A. limonicus* in biological control of thrips, mainly *F. occidetalis* and white flies (both *Trialeurodes vaporariorum* and *Bemisia tabaci*) and that *A. limonicus* is superior to other predatory mites including *Amblyseius swirskii* and *Amblyseius* (*Neoseiulus*) *cucumeris* in predating on thrips in greenhouse cucumber (van Houten, 1995; Hoogerbrugge et. al., 2011;Messelink et. al., 2006).

A. limonicus compared to *A. swirskii*:

- Produces more eggs when feeding on larvae of *F. occidetalis* (3,1 eggs/predatory mite female/day compared to *A. swirskii* that feed on 2,1 eggs/female/day in the same conditions (van Houten et. al. 2008; Bolckmans et. al. 2005),
- Has a higher predation rate on thrips larvae 6,8 larvae per female and day while *A. swirskii* feeds on 4,9 larvae per female and day (van Houten et. al., 2008; Messelink et. al., 2006; Bolckmans et. al., 2005).
- Eats second instar thrips larvae (Koppert-Biological Systems, Info-sheet).
- Reproduces at lower temperatures, down to 13 ^{o}C (Hoogerbrugge et. al., 2011).

How to use *A. limonicus*depends on the situation including type of crop, pest infestation and climate conditions. In most cases, *A. limonicus* is meant to be used curatively since it has shown to be superior other predatory mites when the pest infestation is high (Bolckmans et. al., 2005; van Houten, 1996).

It is recommended to use other predatory mites suitable for preventative protection, e.g. *A. swirskii,* when the infestation is low. Along concrete paths or in hot spots where the infestation gets too high for *A. swirskii* additional *A. limonicus* may be released. A dose of 50-100 mites/m^2 released 2 times with a two weeks interval can be a sufficient dose (De Rodder, pers. comm.). Recommendations on how to use *A. limonicus* in what dose depends on the requirements and can differ from situations and country. The product comes in bottles with carrying materials to be sprinkled on the plant. (Koppert-Biological Systems, Info-sheet).

The interaction between *A. swirskii* and *A. limonicus* may be negative. New information shows the ability of adults of *A. swirskii* to feed on larvae of *A. limonicus* and females of *A. limonicus* feeding on the larvae of *A. swirskii*. Due to this, the best way to release the two species is separately (van

Houten, pers. comm.). *A. limonicus* is not sensitive to diapause which makes it suitable for year round use (Koppert-Biological Systems, Info-sheet).

A. limonicus may be important in crops with other circumstances that are unsuitable for *A. swirskii* e.g. cultures with lower growing temperatures. In protected strawberries studies have shown the efficiency of *A. limonicus* in controlling both *F. occidentalis* and white flies (Hoogerbrugge et. al., 2011).

A. limonicus will probably been seen as standard control agent within biological control of protected strawberries in Belgium and The Netherlands (De Rodder, pers. comm.).

2.6 Chemicals to control thrips

2.6.1 Conserve® SC, *spinosad*

Traditionally the insecticide Conserve® SC (Dow AgroScience), with the active ingredient spinosad, is used against thrips in cucumber cultivation in Sweden (Jordbruksverket, 2012). Conserve® SC is affecting the insect's nervous system causing it to stop feeding. It is effective both by ingestion and contact exposure (Dow AgroSience Info sheet). However, studies have shown that *F. occidentalis* has developed resistance against spinosad (Loughner et. al. 2005).

According to Koppert's list of side effects Conserve® SC can harm predatory mites such as *A. swirskii* and *A. cucumeris*. The persistence can be up to 1-2 weeks. Information of its effect on *A. limonicus* is not available at the moment.

2.6.2 Vertimec®, *abamektin*

The chemical Vertimec® (Syngenta), with the active ingredient abamektin can also be used to control thrips in cucumber cultivation in Sweden. Vertimec® is affecting the insect's nervous system, by ingestion, resulting in paralyzing and thereby death. Vertimec® is only allowed to be used with 10 days waiting period (Jordbruksverket, 2012 and Syngenta-InfoSheet). According to Koppert's list of side effects, Vertimec® does harm predatory mites such as *A. swirskii* and *A. cucumeris*. The persistence will be up to 1-2 weeks. Information of its effect on *A. limonicus* is not available at the moment.

Other preventive measurements to control greenhouse pests are to sanitize the greenhouse and its interior and manage the weeds (Jordbruksverket Compendium). Some kind of hot treatment, i.e.

empty greenhouses with closing ventilation windows were temperature are allowed to rise as much as possible may also have an effect.

3. Greenhouse experiment

The aim with this study was to investigate if the newly launched predatory mite *A. limonicus* could be used as an efficient biological control agent against thrips in cucumber production in Sweden.

As preventatively control against thrips, slow releasing bags with the predatory mite *A. swirskii,* was used in all greenhouses. Since the predatory mite *A. limonicus* is intended to be used curatively and as a compliment to *A. swirskii,* selected areas were treated with additional *A. limonicus.*

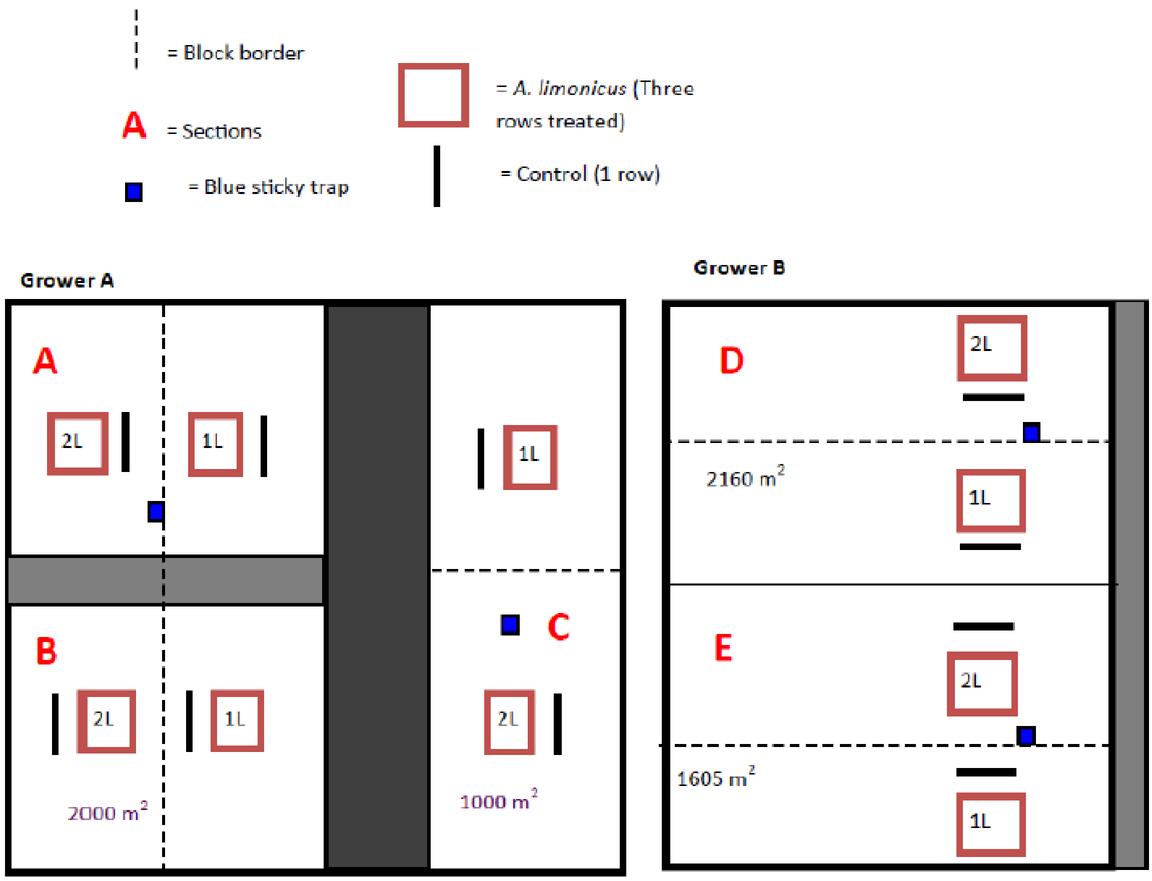
The two compared treatments were:

1. *A. swirskii* in the control areas.
2. *A. swirskii* and *A. limonicus* in treated areas.

The greenhouse trials were conducted during the season 2012 at two different greenhouses near Helsingborg, Scania in Sweden. The location is interesting due to a relatively high presence of ornamental producing creating a high thrips pressure, mainly of *F. occidentalis.* One of the growers have had documented presence of *F. occidentalis* in 2011. The grower also has the experience of thrips causing some problems in the production. The other grower does not have presence of *F. occidentalis.*

4. Material and methods

Picture 3 shows a schematic view of the experimental trial design. The trials were conducted at two different growers, called Grower A and B. At grower A, the greenhouses was separated into three different sections, section A, B and C. Section C was placed in a separate greenhouse section while A and B were in the same greenhouse section. At grower B the sections were named D and E and they were placed in different greenhouse sections.



Picture 3. A schematic picture of the trial design of the two greenhouses. The block borders are indicated with spotted lines, the sections are given with letters A to E. Approximate places for the sticky traps and treated areas and control rows are shown.

The plants were maintained by the growers according to conventional practices. The variety 'Euphoria' was used. At grower A, the plants were planted in pumice containers. At grower B, the plants were planted on rock wool slabs. The climate was kept at a temperature of 20 °C at day and 18 °C at night. The RH was kept at 80 %. In all greenhouses the cucumbers where planted in double rows, with a planting density of 1, 5 plants per square meter. The sizes and the setting of the greenhouse sections are shown in Picture 3.

Before planting the second crop, grower A empties and cleans the greenhouses and leaves it empty for two weeks. During this period the ventilation is open and the temperature reaches a maximum of about 35 ^{o}C during warm days. Grower B transplants the new plants the day after emptying the greenhouses. Both growers treated the newly planted cucumber plants with Vertimec® directly after transplanting.

Due to different pest pressure between and within greenhouse sections, every section was divided in two blocks and statistically analyzed pairwise. Every block contained three rows where *A. limonicus* were released and one row served as the control. The treated rows and the control row were kept close in every block to take into account the possibly different pest pressure within the greenhouse sections. In between the control row and the treated rows one row was left untreated to minimize the risk of in/out-flying thrips and spread of *A. limonicus* (e.g. by harvesting or nursing the plants etc.).

4.1 Assessments of thrips

The presence and density of thrips was monitored weekly during the season by using blue sticky traps (Borregaard Bioplant,10 x 22 cm) (Brodsgaard, H. F., 1989). With the sticky traps the thrips population was overviewed and estimated in the greenhouses. One trap per greenhouse section was used; the first traps were set up in the greenhouses approximately five weeks after culture start. From the traps *F. occidentalis, T. tabaci* and undetermined thrips where noted on both sides. The greenhouses were also visited every week to estimate the thrips situation.

When the first adults of *F. occidentalis* where observed on the plants, 20 randomly selected flowers where checked for adult *F. occidentalis* in each section (A or B and C) to get an overview of the thrips situation prior to transplanting.

4.2 Dose and Application

In the first crop, Grower A used slow releasing bags with *A. swirskii* (250 mites per sachet) two times. Grower B used bags with *A. cucumeris* (1000 mites per sachet) and 10 weeks later, bags with *A. swirskii* (250 mites per sachet) in the first crop. The bags where placed on every third plant, about one meter from the ground. Due to a high presence of *T. tabaci,* additional bottles with *A. cucumeris* were released in section E (100 per m^2) and bottles with *A. swirskii* where released in section D (100 per m^2) a couple of weeks prior to transplanting the second crop.

After transplanting the second crop, slow release bags with *A. swirskii* were used preventatively in all greenhouse sections as basic protection against thrips. Four weeks after transplanting, these slow release bags with *A. swirskii* (250 mites per sachet) where released in all greenhouse sections, except in D where they were introduced 5 weeks after transplanting date.

The dose of *A. limonicus* used was based on recommendations from Koppert BV. 100 mites per square meter were released two times with two weeks in between. The first release was carried out in the second crop, four weeks after transplanting. The cucumber plants were about 2 meters high and side branches were developed. Every block treated with *A. limonicus* contained 60 cucumber plants, in an area of 40 square meters.

The mites where released directly from the bottles. The bottles were turned and gently shook to allocate the mites evenly within the carrier material inside the bottle. The material was sprinkled on leaves in three double rows per block.

The amount of material to sprinkle in every row was calculated from the 1 liter bottle that contained 12 500 pcs *A. limonicus* in carrier material per liter. In every row, 0,11 liters of carrier material (containing 1375 pcs *A. limonicus*) were dispersed.

Three weeks after the last application of *A. limonicus,* one sample with predatory mites was collected from one block in every greenhouse section. The block was randomly chosen. The collected predatory mites were taken from rows that had been treated with *A. limonicus*. 30 mites per block were collected with a small paintbrush and stored in 70% ethanol and sent to Koppert BV. for determination to species level. 10 mites per sample were determined.

4.3 Assessments

After transplanting, data was recorded once a week in the treated rows and the control rows. The recording was done from randomly chosen leaves with a diameter of approximately 10 – 15 centimeter and from flowers in full bloom. Flowers that were visited by other insects e.g. ants and honeybees were avoided.

In every block, 10 leaves and 10 flowers where sampled in the rows treated with *A. limonicus* and in the control row. Adult *F. occidentalis,* adult *T. tabaci,* thrips larvae, adult undetermined thrips and predatory mites where counted from the lower sides of the leaves using a 10 x magnification glass. Adult thrips where randomly sampled for identification by microscope in laboratory.

In the results, the number of recorded thrips in each category (adult *F. occidentalis,* adult *T. tabaci* and thrips larvae) on leaves and flowers have been assembled and regarded simply as thrips. The reason is the low catches of thrips in each category and the absence of any significant differences. The decision to group all species and stages of thrips into one is based on the fact that the predatory mites are generalists and thus affect the population of both *T. tabaci* and *F. occidentalis* (McMurtry, 1997).

Due to *A. limonicus* efficiency in predating on both larvae stages, it would have been interesting to keep the different larval stages separated . However, this was not possible in the field situation.

4.4 Statistical analysis

Due to the different prerequisites of the trial sites, the statistical analysis was made for each grower separately. A Two-way T-test at 5% was used for analysis. Each time point was analyzed separately.

5. Results

5.1 Grower A

5.1.1 Data collection from flowers prior to transplanting

Table 1, shows the number of thrips per flower during the end of the first crop, prior to the transplanting in Section A and B (one greenhouse) and Section C.

X indicates the date of the first observation of *F. occidentalis* in flowers. The counting of thrips in flowers prior transplanting was not done in section D and E since no *F. occidentalis* were found at grower B.

Table 1. Numbers of *F. occidentalis* found in flowers in the first crop in section A and B or section C.

Days after start in first crop	Section A and B	Section C
49	X	X
56	0	0
63	0,1	0,1
70	0,1	0
77	0,2	0,1
84	0,35	0,2
91	0,3	0,05

5.1.2 Monitoring sticky traps

The number of thrips found on sticky traps is shown in figure 1 and 2 below. The results from section A and C are displayed separately. In section A (figure 1), the number of *F. occidentalis* increased between day 60 and 100, with a maximum number of 47 thrips/sticky trap (ST) on day 70. The first *F. occidentalis* was recorded from the first ST. After day 98, the greenhouse was emptied for two weeks in association with the transplanting. There were no sticky traps in the greenhouse during this period (between day 98 and 119).

After 42 days, the first *T. tabaci* were recorded. Prior to transplanting, the population of *T. tabaci* had reached its maximum with 10 thrips/ST. After transplanting, the density of both thrips species never exceeded 5 thrips/ST. Population density monitored by sticky traps and by counting thrips found in flowers was similar throughout the trial period.

In section C (figure 2), the first *F. occidentalis* was recorded after 14 days. The presence of *T. tabaci* was only recorded once on a sticky trap in Section C, on day 147. Contrary to section A, the thrips population in section C does not exhibit any significant changes during the season. Over all, the thrips population density in section C was lower than in section A.

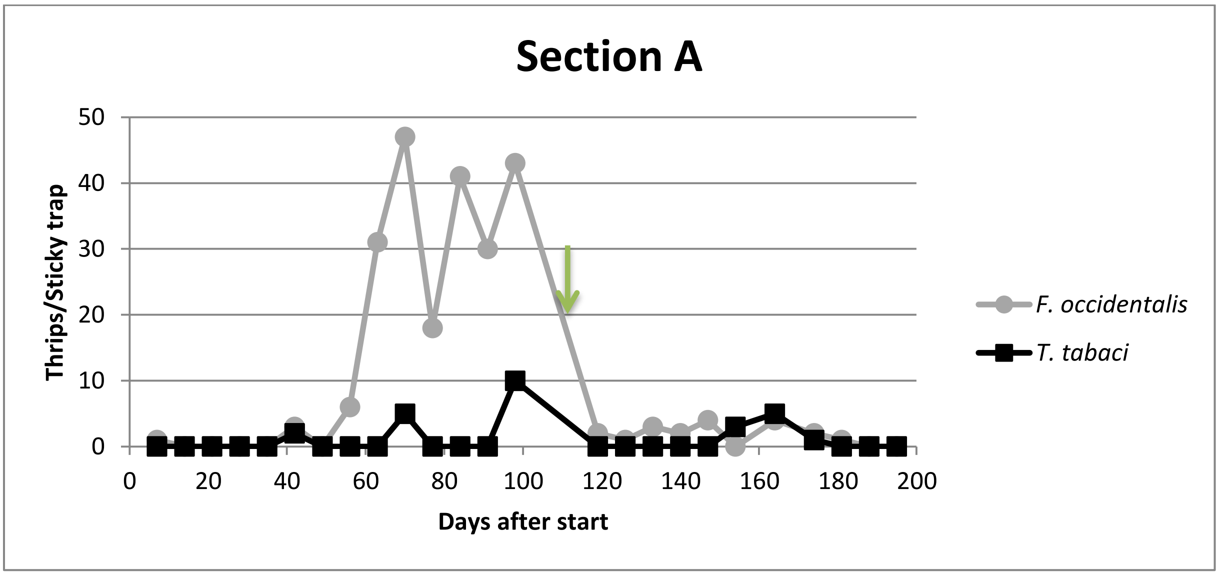


Figure 1. The number of *F. occidentalis* (•) and *T. tabaci* (▪) caught on sticky traps during 200 days of the season in Section A. Days after start is referring to the number of days from when the first sticky trap was introduced. The arrow indicates the time for transplanting.

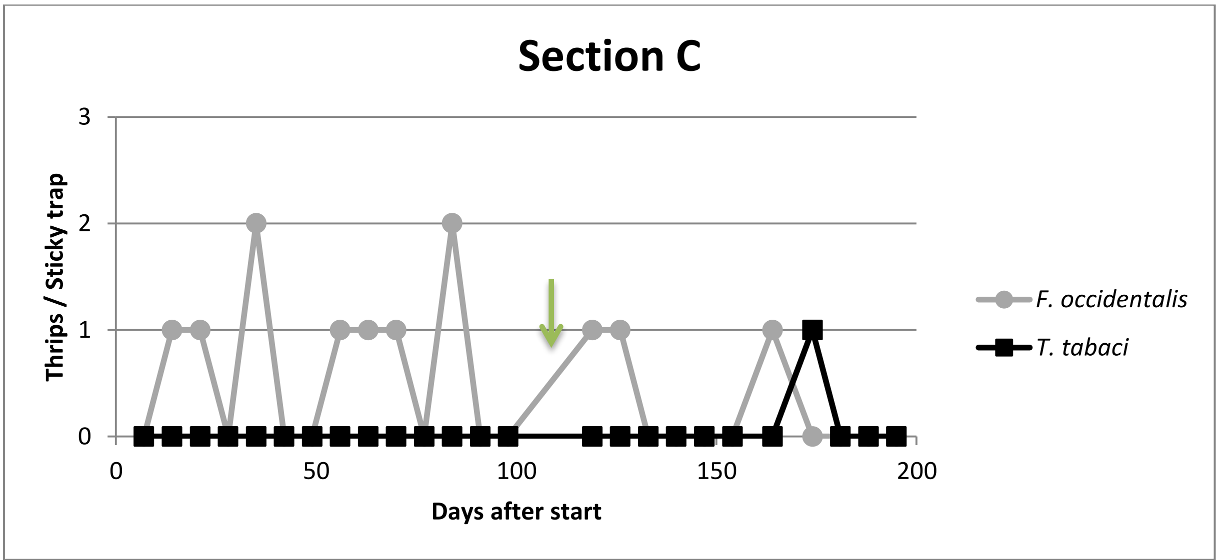


Figure 2. The number of *F. occidentalis* (•) and *T. tabaci* (▪) caught on sticky traps during 200 days of the season in Section C. Days after start is referring to the number of days from when the first sticky trap was introduced. The arrow indicates the time for transplanting.

5.1.3 Monitoring Thrips and Predatory Mites on Plants

The recordings of thrips and predatory mites on plants started two days after the transplanting at grower A, in section A, B and C. Thrips were found from the start and their density increased slightly until day 23. Their density is slightly higher in the control area on day 23, a few days after the mites were released. Following the release of predatory mites, the thrips population decreases in both treated and control areas and increase slightly again after day 50.

Predatory mites were released after day 16, which resulted in an expected increase in predatory mite density. A few mites were recorded on day 9 and 16 (Figure 4). On day 16, prior to the release of both *A. swirskii* and *A. limonicus* in the second crop. The control areas had significantly lower number of predatory mites (0,07 pred. mites/leaf in the area where *A. limonicus* were released vs. 0 pred. mites/leaf in the control area, P-value=0.0250). These recorded mites were probably *A. swirskii* remaining from the first crop of cucumber. However, due to the low densities in which they occurred, they are not expected to have affected the experiment.

The density of predatory mites increased up to day 40. Up to day 30 there seems to be slightly higher densities in the areas were *A. limonicus* has been released. However, following day 40 the area treated two times with *A. limonicus* exhibited a smaller population of predatory mites compared to the control. The difference is significant on day 40 (1,27 resp. 2, 47 mites /per leaf and flower, P-value=0,0475) and on day 57 (0,133 resp. 0,383 mites /per leaf and flower, P-value=0,0221).

In the control area the mite density increased continuously over a period of approximately 4 weeks, confirming the ability of the *A. swirskii*-product to support the crop with a steady supply of predatory mites.

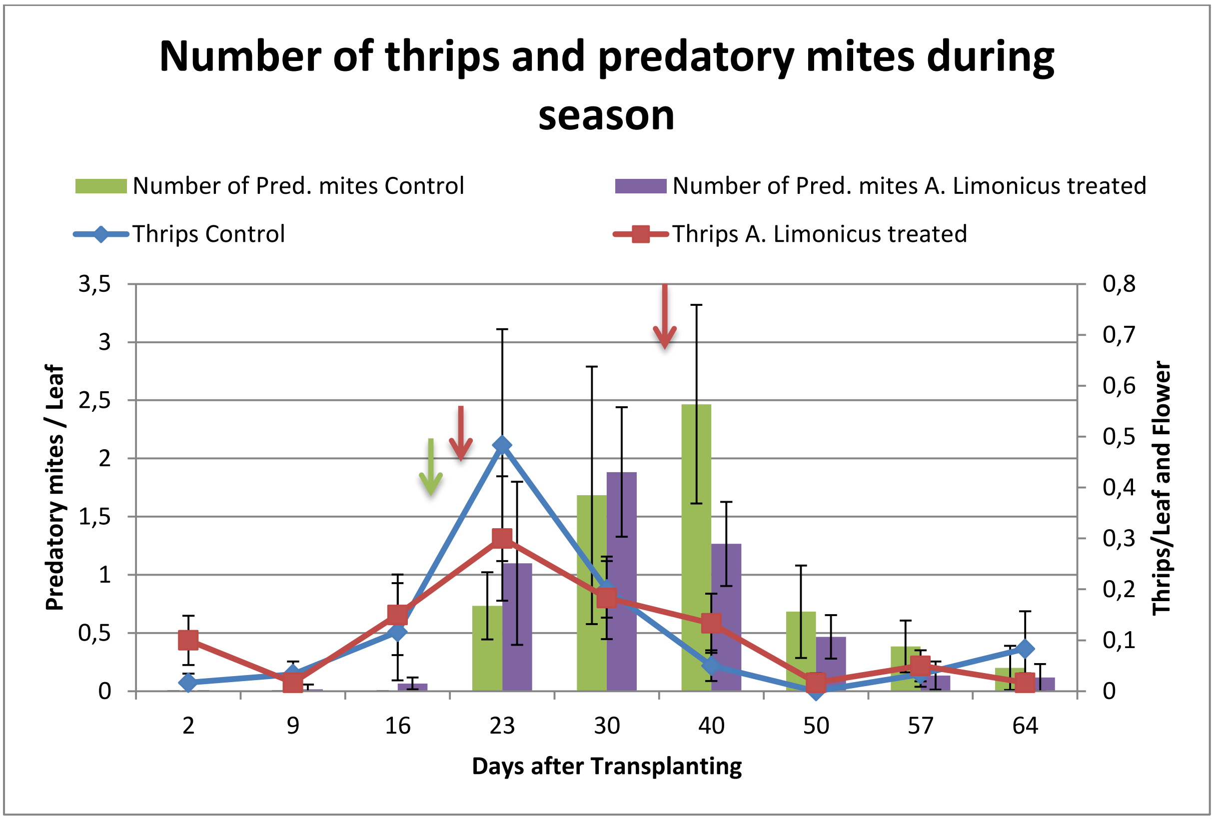


Figure 4. The mean number of thrips and predatory mites found after transplanting, on leaves or flowers in the area treated with *A. limonicus* and in the control. The number of thrips is indicated on the right axis. The number of predatory mites in indicated on the left axis. The value is a mean value with standard deviation based on all six blocks inside the greenhouse. The green arrow indicates the time of release of *A. swirskii* and red arrows indicate the two *A. limonicus* releases.

5.2 Grower B

5.2.1 Monitoring sticky traps

Only *T. tabaci* has been recorded from sticky traps at grower B, section D and E (see Figure 3). After day 100, there was a slight increase in the thrips population in both section D and E. The highest thrips density (18 thrips/ST) was recorded on day 140 in section D. This might be due to that the transplanting had taken place some days prior to the removal of the sticky trap in question. The highest thrips density in Section E (7 thrips/ST) was found on traps from day 154 and 174.

The transplanting in Section E was done two days before removing the trap from day 126, but does not seem to affect the thrips population. Sticky traps from Section D were missing three times during the season; they were probably removed by mistake. The result from section D and E is added in one diagram since it only shows presence of *T. tabaci*.

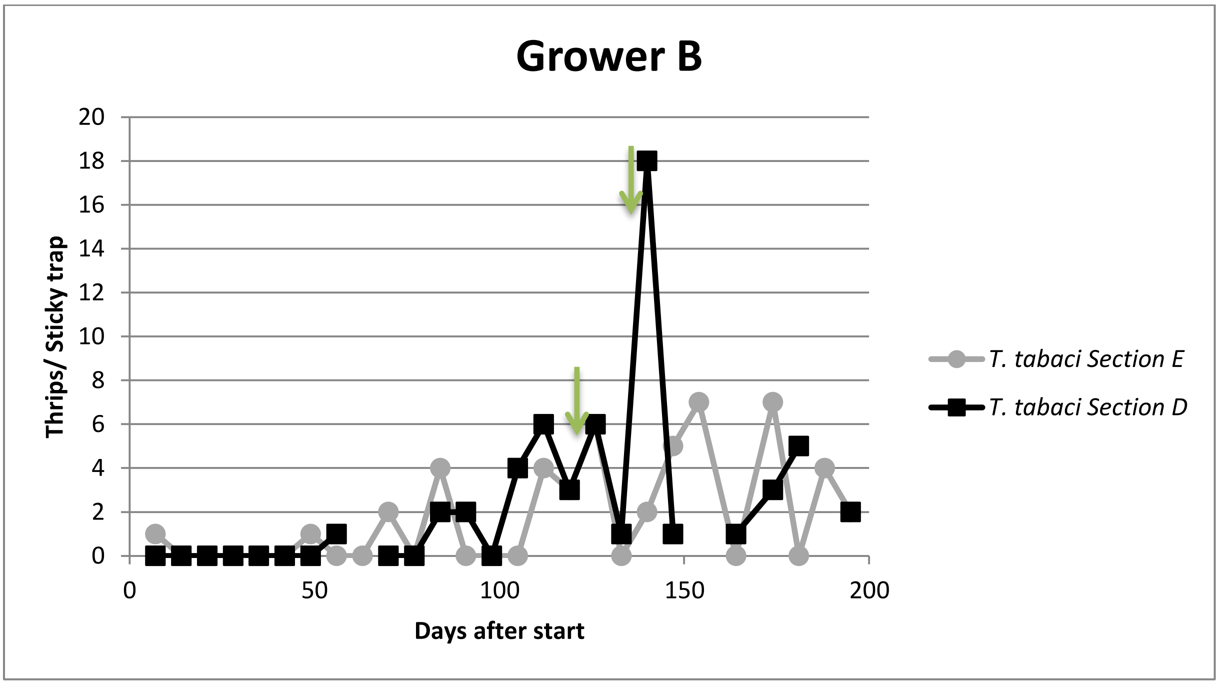


Figure 3. The number of *T. tabaci* in section E (•) and the number of *T. tabaci* in section D (▪) caught on sticky traps during 200 days of the season in Section D and E. Days after start is referring to the number of days from when the first sticky trap was introduced. The arrows when transplanting was made in each section. The first arrow shows the day in section E (some days prior day 126) and the second arrow shows the day in section D (some days prior day 140). Missing values are not shown in the figure.

5.2.2 Monitoring Thrips and Predatory Mites on Plants

At grower B, there were no significant differences between the *A. limonicus* treatment and the control. The transplanting in section D occurred 14 days after transplanting in section E, but the data from section D and section E has been grouped into one data-set, shown in Figure 5.

The amount of thrips peaked with a density of 1,65 thrips/leaf and flower on day 35. This might be due to the lack of hand sized leafs. Consequently, the sampling was made from older leaves where the thrips population may have been more developed. In the control area, the thrips increased up to day 30 in the control area. After day 30 it decreased.

Regarding the predatory mites, their densities increased both in the treated area and in the control following the release of *A. swirskii* and first release of *A. limonicus*. The density of predatory mites was higher in the control than in the treated area after the second release of *A. limonicus*, although not supported statistically. This is in accordance with the results from grower A, and further supports the theory about a negative interaction between the two mite species at high densities and shortage of prey.

The high number of predatory mites on day 44 is probably a result of the situation in section D where both *A. swirskii* and *A. limonicus* were released later than in section E. The high standard deviations, especially for the number of predatory mites, confirm the large variations in the two different sections E and D due to the late replanting date.

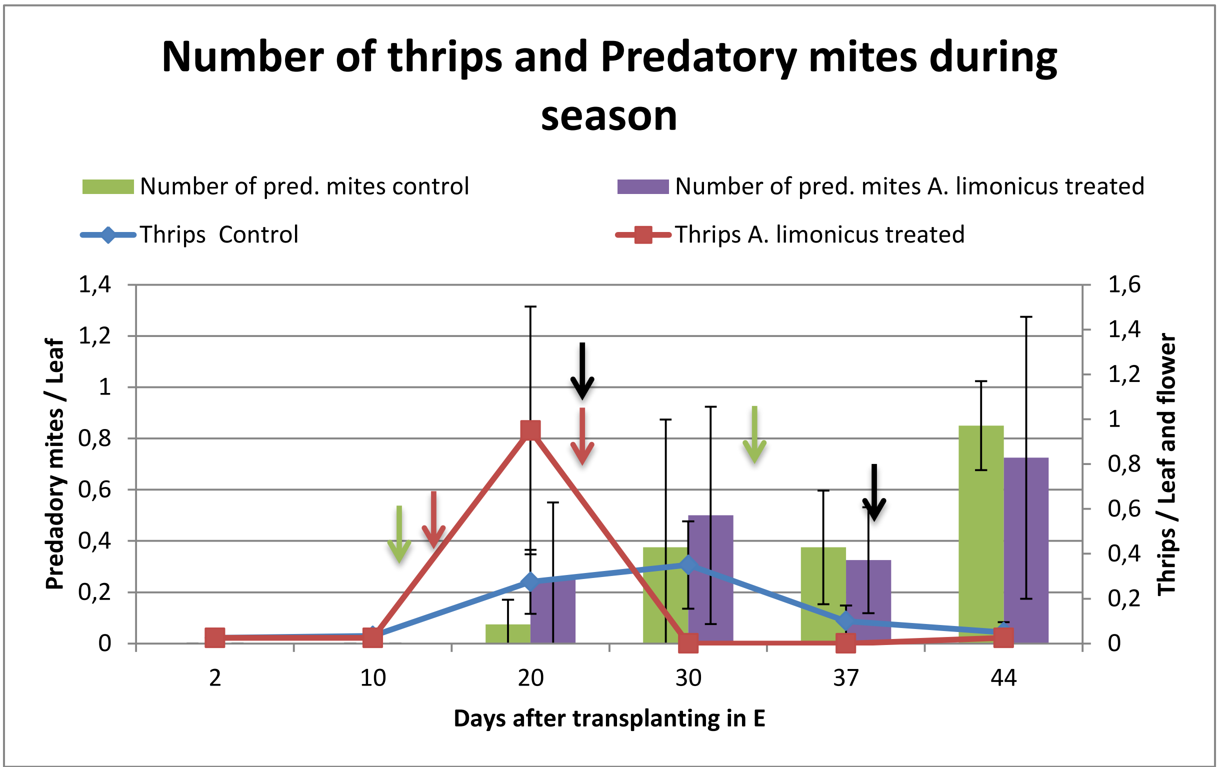


Figure 5. The mean number of thrips and predatory mites found after transplanting, on leaves or flowers in the area treated with *A. limonicus* and in the control. The number of thrips is indicated on the right axis. The number of predatory mites in indicated on the left axis. The value is a mean value with standard deviation based on all four blocks inside the greenhouse. The green arrows indicate time of release of *A. swirskii,* first in section E and second in section D. Red arrows indicate time of release of *A. limonicus* in section E and the black arrows indicate time of release of *A. limonicus* in section D.

5.3 Mite samples

Table 2 shows the number of predatory mites determined by Koppert BV. The mite samples are collected from both growers and all sections, A, B and C (grower A) and D and E (grower B). The result indicates that there are more *A. limonicus* than *A. swirskii* on the plants.

A. limonicus might have a competitive advantage compared to *A. swirskii.* The unidentified predatory mites is assumed to be *A. swirskii* since none of the growers have released the predatory mite *Amblyseius andersoni,* however contamination from the producer may also be an explanation.

Table 2. Number of *A. limonicus* and *A. swirskii* determined to species level from section A, B and C (grower A) and D and E (grower B). * Could be *Amblyseius andersoni* but most likely *A. swirskii.*

Grower	Section	*A. limonicus*	*A. swirskii*	Unidentified, most likely *A. swirskii** but not *A. limonicus*
A	A	1	4	5
A	B	7	1	2
A	C	4	3	3
B	D	6	4	0
B	E	9	0	1
	Total:	**27**	**12**	**11**

5.4 Other Observations

- *F. occidentalis* was observed on weeds outside the greenhouse of grower A after the transplanting. This indicates that *F. occidentalis* possibly can fly in and out of the greenhouses, thereby forming natural refuges from which they might recolonize the greenhouse after e.g. an insecticide wipe-out.

- During the first weeks of the trial, many males of *F. occidentalis* were caught on sticky traps. Later, exclusively females of *F. occidentalis* were caught.

- Dark colored thrips, recorded as "others", appeared on sticky traps and flowers mainly from the middle of summer to late summer. The highest recorded number was 3 thrips /ST.

- Adult *F. occidentalis* were mainly found inside flowers and only occasionally on leaves. Adult *T. tabaci* were exclusively found on leaves. In some cases, thrips were observed on the upper side of the leaves. However, these were not recorded. Larvae of thrips and predatory mites were only found on the lower side of leaves.

- Predatory mites were occasionally observed in flowers, indicating their search for thrips larvae.

6. Discussion

The situation at Grower A is interesting as the presence of *F. occidentalis* makes the situation more severe than at Grower B. The area is known to have a certain pest pressure of *F. occidentalis*, in part due to the concentrated cucumber production, but mainly because of the ornamental producers situated in the area. Thus, it serves as an example of how the world trade of ornamentals increases the risk for infestations of resistant *F. occidentalis*. Growers in the area will probably, to a higher degree, have to depend on solutions complementary to conventional insecticides such as more efficient predatory mites, as a part of an IPM strategy and for the future control of *F. occidentalis*. Efficient control agents, biological as well as chemical, are crucial key components in facilitating a successful implementation of IPM programs. *A. limonicus* is interesting since it is a supplementary product with potential to be used in hot-spots instead of chemical treatment to suppress the pest.

Due to the relatively high thrips pressure during the end of the first crop, the significant reduction, at grower A, after transplanting was unexpected. The explanation might be that the survival rate and development time of thrips emerging from pupae was severely affected. Both by the lack of food source but also the increased temperature when the greenhouse was emptied for two weeks. During warm days in the empty greenhouse the temperature could raise up to 35 ^{o}C. However, the fact that *F. occidentalis* have been found outside of the greenhouses throughout the season indicates that a second recolonizing following the transplanting could have been possible. One could speculate that this kind of "heat-treatment" of empty greenhouses could act as a complement in an IPM strategy, aiming to reduce diseases and pest pressure before planting the second crop.

Whether the thrips reduction at grower A, after the transplanting, was due to the Vertimec® treatment, sanitation or to the combined heat treatment/starvation cannot be answered in this study. External factors, e.g. weather conditions, could at least in part also explain the absence of recolonizing thrips.

Further studies investigating how *F. occidentalis* colonizes greenhouses from surrounding areas could be useful in predicting the risk of infestation. Based on this information, control actions can be developed. On the other hand, these kinds of studies are quite labor intensive.

One of the difficulties with chemical control of thrips is their short life cycle, resulting in many generations per year in greenhouse conditions. Conserve® SC and Vertimec® targets only the larval stages, meaning that the periods for efficient application of chemicals are very short. In this aspect the predatory mites that reproduce and continuously search for larvae on the plants have an advantage over chemicals.

To create a good IPM strategy, the growers need useful and manageable tools to make decisions on control actions. Biological control plays a great role in present and in future plant protection, but there is also a need for selective chemical agents. The use of such products does, however, require detailed information regarding the chemical side-effects on different biological control agents , posing a need for further studies.

The situation at Grower B differs from that at Grower A. The location, technical facilities and the type of greenhouse is different. The thrips population is also different, *T. tabaci* is the species present and *F. occidentalis* has not been recorded at the site. Since insecticides targeting *T. tabaci* still seem efficient, one could argue that there is no urgent need for *A. limonicus* in conventionally grown cucumber. However, e.g. Vertimec® has a negative impact on natural enemies and is a non-selective chemical. If the grower has already released biological control and is forced to use chemicals that will kill the population of natural enemies it will lead to extra costs. The future may also be different regarding available insecticides, pest resistance as well as pests present. In organically grown cucumber or within an IPM strategy, *A. limonicus* could still be useful even if chemicals are available.

The data collected from flowers of the first crop at grower A's greenhouse, some weeks prior transplanting shows a maximum presence of 0,35 *F. occidentalis* per flower. According to Shipp et. al. (2000), the economic injury level of *F. occidentalis* calculated from control costs, yield potential and fruit prices is in the range of 3 to 7,5 adults per flower. However, this study is performed under Canadian conditions. Sweden and Canada cannot be compared readily, as control costs and yield potentials are likely to differ significantly between the two countries. Establishment of a similar threshold value for Swedish conditions would be a key-component in building good models for insecticide use or other control measures.

F. occidentalis were almost exclusively found inside the flowers and only occasionally recorded from leaves. This is in line with the information available on *F. occidentalis.* Because it aggregates inside flowers, counting of thrips found in flowers provides an important estimation of the infestation of *F. occidentalis*. It might also be a useful practice for the growers in assessing presence of *F. occidentalis*, as it can be done before any damage is observed on the fruits. Counting of thrips in flowers is relatively easy to perform, since thrips are easily spotted inside the yellow flowers. By blowing gently into the flower the thrips get disturbed and starts to move around.

Since it is hard to determine the species only by observing thrips in field, growers need support by experts to differentiate between e.g. *F. occidentalis* and *T. tabaci*. Using sticky traps that are monitored regularly also gives an overview of the thrips situation in the greenhouses. Blue sticky traps are especially useful as they primarily attract thrips (Brodsgaard, H. F., 1989). These kinds of tools provide important information for the assessment of suitable control measures.

T. tabaci was almost exclusively found on the leaves. The counting of mites on leaves is more difficult than counting thrips from flowers, since the leaf area might be large and the physiological growth stages might differ from leaf to leaf.

By looking at *T. tabaci* present on sticky traps, the growers can estimate the level of infestation and make decisions about control measures. When using predatory mites preventatively (e.g. *A. swirskii*), it is important to take into account that it is more efficient if the release is done before the pest is visible. Overreliance on sticky traps may result in false negatives as a blank sticky trap might simply reflect a small population. Thus, it might still be necessary to release predatory mites to keep the pest infestation low.

At grower A, the thrips population does not seem to follow the same pattern in section C as in section A, with the increase of the thrips population before transplanting not being as clear in section C. The sticky traps were placed equivalently in the two sections, A and C. The differences might be due to actual differences between the chambers or simply by chance. Section C is approximately half the size of section A. It might suffer from increased edge effects and the increased area to volume ratio might also affect airflow, thus thrips population migration/immigration patterns.

Increasing the concentration of sticky traps would enable a more detailed study on thrips population establishment and development, both spatially and temporally. One way to facilitate such a study, while keeping the amount of sticky traps at a manageable level, would be to randomly place sticky traps at different places associated with the trial areas inside the greenhouses as described by Shipp et. al. (2000).

Interestingly, the sticky traps at grower A indicated a sex shift in the *F. occidentalis* population during the season. At the beginning of the season there were mostly male thrips caught on the traps, while in the middle and at the end of the season exclusively females were caught. This is in line with the fact that *F. occidentalis* reproduces by facultative pathogenesis. Thus, in the beginning of the season there are fertile males searching for females while later, during the season, fertile females are flying around to disperse their eggs.

At grower B, the two sections D and E do not seem to differ in terms of thrips population. The population is rather stable with some minor fluctuations from day 50 and throughout the season (May to the end of September). However, in association with the transplanting a deviating peak value of 18 thrips/trap was recorded, which might have been due to the disturbance caused by the transplantation.

Although it is not reflected in the sticky trap records, the thrips caused leaf damage at the end of the first crop which resulted in a subsequent release of the predatory mites *A. swirskii* and *A. cucumeris* at grower B. During the second crop leaf damage was kept at low levels. This could indicate that the sanitation and chemical treatment with Vertimec® created a sufficient suppression of the trips, although it was not clearly seen on the sticky traps. It could also support the idea that the snapshot provided by the sticky trap record might not be completely reliable. As previously discussed, future studies would clearly benefit from a better spatial coverage of sticky traps.

The pattern of the predatory mite population seen in the control rows, especially in results from grower A, confirms the ability of the slow-releasing bags with *A. swirskii* to support the plants with predatory mites for 4-5 weeks. To obtain optimal preventative control against pests, new bags should be put out every 4-5 weeks period as recommended from the producers. In this case the renewal of the bags was not necessary since the season was ending. However, during spring and summer this may be crucial to obtain efficient thrips control. To get reliable statistical analysis of the trials data from section D and E at grower B, the data from every weekly collection was assembled. The two weeks delay of the transplanting for section D made the analysis of the thrips and predatory mite situation somewhat unreliable. The trend, at grower B, is similar to that of grower A, with increasing total predatory mites and later decreasing total predatory mites in the rows treated with *A. limonicus.* The pattern of bags supporting plants with *A. swirskii* found at grower A was not clear at grower B. This might be a consequence of the different times of release of the *A. swirskii* bags in the two sections. It could also be a result to different climate condition or application of chemicals, not necessarily intended to target the thrips.

As a result of the problem with insufficient numbers of recorded thrips in every category, the decision was made to assemble all thrips (in all stages) in one group to get a suitable data-set. The decision was also based on the assumption that both larvae and adult thrips indicate potential damage, even though the larvae are the targets for *A. limonicus*. Counting the larvae would have been interesting, because of their direct interaction with *A. limonicus*. However, this requires laboratory facilities and more thrips than what were available in this study. If the thrips infestation would have been higher, the reduction of larvae per leaf might have been noticeable. However, the advantage of putting all thrips in one category is the elimination of errors due to incorrect species classification in field. Random thrips samples from field sites were controlled with a microscope to confirm a correct taxonomic classification. However, a 10 x magnification might be insufficient for taxonomic classification of different thrips species.

Dispersing 100 *A. limonicus* per m^2 two times may have been too much. After the second release, there were fewer predatory mites in the areas treated with *A. limonicus* than in the control. This was probably due to the competition on the plant resulting in the species predating on each other. This can be seen as an indication of the dose being too high in relation to the amount of thrips.

The release of *A. swirskii* and *A. limonicus* at the same time may have increased the negative interaction between them, due to predation on each other, enhanced from the lack of prey. The negative interaction between *A.swirskii* and *A. limonicus* might have been pronounced in this trial due to their simultaneous release and the lack of prey. In order to avoid this, it is recommended not to release the two products at the same time (van Houten, pers. comm.). Since the thrips control in the area treated with only *A. swirskii* was sufficient, in this case, the use of *A. limonicus* was redundant.

After the second release, a reduction of predatory mites in the rows treated with both *A. swirskii* and *A. limonicus* were seen at both trial sites. The number of predatory mites was higher in the rows only treated with *A. swirskii*. This could indicate that the predatory mites have been predating of each other.

The mite samples showed that both predatory mite species had the ability to survive on the plants. The number of *A. limonicus* was slightly higher, even if the unidentified mites were assumed to be *A. swirskii* in the calculations. This might be a coincidence but could be related to the higher predation rate of *A. limonicus,* increasing their fitness over *A. swirskii.* It could also be a result of that the amount of released predatory mites of *A. limonicus* per square meter was higher than the released *A. swirskii* mites per square meters.

There is potential to use *A. limonicus* in hot-spots or highly infested areas and the product can be supplementary to other predatory mites used against thrips and whitefly. None of the growers has had problems with whiteflies.

In further studies it would also be interesting to investigate how *A. limonicus* preform in Swedish conditions when both thrips and whiteflies are present. Since both growers use *A. swirskii* preventatively (which also feed on whiteflies) occasional infestation of whiteflies should be kept at a low level. The availability of prey from both whiteflies and thrips would be expected to favor *A. limonicus*.

6.1 Conclusions

- Treatment with *A. limonicus* did not improve the control of thrips, probably because of to low thrips infestation.
- The number of thrips decreased when *A. swirskii* and *A. limonicus* were released after replanting. The reduction of thrips was as adequate in the control rows as well as in the treated rows. This proves *A. swirskii* to be sufficient at this pest level.
- The release of both *A. swirskii* and *A. limonicus* at the same time might have created a negative interaction due to cannibalistic behavior.

6.2 Improvements and difficulties

- The negative interaction between *A. swirskii* and *A. limonicus* might be prevented to some degree by separating their releasing time by one or two weeks.
- Evaluating more blocks or replicates per grower or counting a larger number of leaves and flowers per block may have provided better data for the statistical analyze. On the other hand, more blocks or replicates to count are time consuming.
- The delayed transplanting at grower B (due to the two weeks interval between section D and E) complicated the data analysis.
- When performing field trials it is important to avoid potential edge effects. The problem with greenhouses is that pest infestation often is higher along the concrete paths or at the end of the rows. *A. limonicus* is intended to be used in these hot-spots.
- Another way of studying the controlling effect of *A. limonicus* on thrips would have been to do an isolated trial, where both thrips and predatory mites are inoculated. On the other hand, these kinds of studies have already proven *A. limonicus* to be efficient in thrips control.

6.3 Suggestions for further studies

- Trials in cucumber greenhouses with higher thrips pressure and with whiteflies present would give more information about how *A. limonicus* perform under Swedish conditions.

Evaluation of crop damage (misshaped cucumbers) is also important, especially when *F. occidentalis* is present.

- Trials in other cultures where the temperature is lower, e.g. ornamental plant production or protected strawberries, where problems with both whiteflies and thrips are common. In these cultures there is need for a product that can be released in hot spots where *A. swirskii* is insufficient. However, difficulties may occur when evaluating the effect of *A. limonicus* in ornamental plant production since it performs best when infestation levels are high, at the same time as there is a very low damage tolerance in ornamental production.

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