

alter thrips dispersal from areas of high populations or virus infected sources. This is a quick setup and allows time until the main treatment can be applied or infected plants are removed.

1.3.2.2 Biological control

Acceptance of biological control as a serious control strategy depends on good public relations and education. The beliefs that the use of natural enemies creates new pests and biological control agents are unreliable arose mainly as a result of strong pressure to market natural enemies before they were fully tested. The methods of researching biological control is quite different from that of pesticides but not as expensive as commonly believed. Cost benefit analysis of research and development indicates a 30:1 ratio for biological control and a 5:1 for pesticides (van Lenteren 1990). Many growers have yet to adopt nonchemical approaches to greenhouse crop management because biological and environmental control methods are thought to be more difficult to manage and possibly more expensive (Clarke *et al.* 1994). Incentive for use by the grower is that the cost of the recommended rate of inundative releases of predators for thrips in greenhouse cucumbers is similar to pesticides (Gilkeson 1990).

Biological control agents may be predators, parasites, or pathogens. A predator feeds on its prey by catching it but otherwise lives independent of it. Use of the predatory mites has become an accepted method of controlling thrips (Ferguson 1995). *Amblyseius cucumeris* (Oudemans) [Acarina: Phytoseiidae] is the most commonly used predator in greenhouse cucumber production. With the development of a controlled release system which consists of a bran based culture in a waxed paper sachet of specific porosity, *A. cucumeris* establishes

rapidly with better distribution, and continues to breed and emerge from packs for at least six weeks (Bennison and Jacobson 1991). *A. cucumeris* enters diapause at a critical daylength of 12.5 hours with 22°C day temperature and 17°C night temperature (Gilkeson *et al.* 1990). Diapause affects only female predators by halting production of eggs (Rodriguez-Reina *et al.* 1994). This not only causes a loss of reproduction, but also reduces the functional response since gravid females are the most effective predatory stage (Shipp and Whitfield 1991). A nondiapause strain of *A. cucumeris* was selected by van Houten *et al.* (1995) in which diapause was reduced from 41 to 0 percent in ten generations without a reduction in predatory performance or oviposition rate. Over an eighteen month period, the nondiapausing strain of *A. cucumeris* did not enter diapause under diapause inducing conditions which indicates that it was a stable trait for this predator.

Iphiseius (= *Amblyseius*) *degenerans* (Berlese) [Acarina: Phytoseiidae] has also shown strong predaceous capabilities in the laboratory (Eveleigh and Chant 1981) and its eggs are also more resistant to drought than those of *A. cucumeris* (van Houten and van Stratum 1993). When *A. cucumeris* was tested in the greenhouse against the nondiapausing, drought resistant strain of *I. degenerans*, the latter one was found to have a greater impact on the pest population than *A. cucumeris* (van Houten and van Stratum 1993). *I. degenerans* is considered one of the most promising candidates for biological control of thrips under conditions of low humidity and short day length (van Houten *et al.* 1995). The drawback is that these mites are only predacious on larvae.

Inundative applications of the minute pirate bug *Orius insidiosus* (Say) and *O. tristicolor* (White) [Heteroptera: Anthocoridae] can be used when thrips populations exceed

the control capacity of resident predatory mites. Both nymphs and adults are voracious predators on adult thrips as well as larvae. Adult minute pirate bugs are known to consume one larva per hour, and nymphs are even more voracious (Bailey 1933). *Orius* species are cannibalistic in crowded conditions and until 1989 they were difficult to mass rear (Gilkeson *et al.* 1990). *Orius* spp. are also generalist predators and it was initially thought that thrips control may be impaired if pirate bugs prey on the predatory mites in lieu of thrips. On single leaves in small cages, mortality of *A. cucumeris* due to *O. tristicolor* was inversely proportional to thrips density. Thrips mortality due to *O. tristicolor* was unaffected by *A. cucumeris*; therefore, it may be concluded that these biocontrol agents are compatible (Gillespie and Quiring 1992). In sweet pepper crops, after *I. degenerans* displaced *A. cucumeris*, *Orius* spp. appeared in the crop simultaneously with *I. degenerans* without compromise to thrips control or predatory performance (van Houten and van Stratum 1993). Soil-dwelling predatory mites such as *Hypoaspis* spp. (Bailey 1933) and *Geolaelaps* sp. nr. *aceleifer* (Canestrini) (Gillespie and Quiring 1990) contribute to biological control of thrips by preying on pupating thrips in the soil thereby reducing emergence of adults.

Parasites kill their host by living in or on the host body and therefore depending on it for completion of their development (Anon. 1993). Thrips have shown variable responses in their susceptibility to hymenopterous parasites particularly of the *Ceransius* species (Loomans and van Lenteren 1990). *Eulophid*, or minute wasps, lay their eggs in the young thrips larvae. If the second larval instar is parasitized, the wasp cannot develop successfully but will shorten the adult life of thrips (Lewis 1973). Other natural enemies such as nematodes, mirid bugs, spiders, syrphid wasps, pseudoscorpions all prey on thrips in nature

but have not been developed as applied biological control agents.

Few serious attempts have been made to develop fungi as biological control agents for onion thrips (Gillespie 1986). A pathogen must be ingested to be effective; therefore, method and timing of application are crucial (Splittstoesser 1981). *T. tabaci* has been shown to be susceptible to several species of fungi. In laboratory experiments, *Beauveria bassiana* and *Metarhizium anisopliae* killed a population of thrips within four days. In that same time period, *Verticillium lecanii* killed 85 percent of the population. In greenhouse experiments, *V. lecanii* reduced thrips populations on cucumbers (Gillespie 1986). *Entomophthora sphaerosperma* and *E. tarichium* have also caused epizootics in thrips (Binns et al. 1982). Disadvantages to many of these entomopathogens are that they are generalists and will also kill natural enemies used to control other pests in the greenhouse (Binns et al. 1982), and they are inhibited by fungicides (Shipp et al. 1998).

Availability and quality of biological control agents are controlled by companies producing and supplying growers. Packaging and transport to the growers can adversely affect survival or efficacy of the natural enemies. Healthy control agents in adequate slow release packs should contain a developing culture and be free of mould or ammonia odours (Ferguson 1995).

Detailed information on thrips life history is important to understand biological control by natural enemies. The time spent in stages vulnerable to natural enemies can be decisive for predator impact (van Rijn et al. 1995). Biological control involves more than just releasing natural enemies. It also requires strict monitoring to determine how much natural enemies are contributing to control (Anon. 1993). Hence, in biological control situations,

two crops are being produced - the plant and the beneficial insects (Murphy *et al.* 1995).

1.3.2.3 Chemical control

Adults are the preferred target when using insecticides because they are easier to hit than larvae with the mist sprayers and are also generally more sensitive to the products. Chemical control is seldom effective because thrips are protected in the growing tips of leaves and flowers and it is difficult to expose thrips to pesticides (Shipp *et al.* 1990). Greenhouse cucumbers are more commonly grown as cordons rather than lateral training systems and therefore produce a dense mass of foliage which is difficult to spray, while coverage by fogging and ultra low volume methods is poor (Hussey and Scopes 1985). Timing of applications is essential in maximizing the effectiveness of the pesticide. If an insecticide application is required, the temperature and VPD in the thrips vicinity should be 25° to 30°C and greater than 1.2 kPa for a period of up to three hours after the insecticide is applied (Shipp and Zhang 1998). When the greenhouse climate is modified for only three hours, crop production is not affected and the insecticide is more effective by the immediate contact with the pesticide during flight and when thrips land on the upper leaf surface where most of the deposit occurs. Stomach poisons distributed on leaf surfaces are not effective because thrips only feed on superficial plant tissues. Systemic insecticides are even slower because thrips do not feed on phloem tissues where the insecticide is present (Shipp and Whitfield 1991). If a spray is applied in response to an increase in thrips detection during the previous week, spraying occurs after most of the egg laying by new adults is completed (Allen 1995).

Chemicals as a sole approach to thrips control is becoming either less effective or less acceptable environmentally or by the public (Lewis 1997a). In an IPM programme, the use of pesticides remains necessary for two reasons. First, there are a number of pests and diseases that cannot yet be controlled by their natural enemies. Second, pesticides support biological control in case the predators or parasites are temporarily unable to control the pest (van der Staay 1991).

Pesticide application in the greenhouse results in residual effects that are different from those observed in the field and therefore submitted to more stringent pesticide regulations. Temperature, relative humidity, and air transfer in an enclosed environment may affect pesticide movement and breakdown rates (Matteoni *et al.* 1993). In addition to the obvious consideration of environmental and worker safety, and the development of resistant pest populations, a major concern of pesticide use in greenhouses is the effect on biological control agents. It is important to know the life cycle and feeding habits of the natural enemies because pesticides affect predator and parasite populations differently. Predators are most susceptible because they consume prey, accumulating residues over time and thereby becoming less efficient due to reduction of their populations. Parasites feed on only one host; however, as they emerge from their cases, the pupae may be poisoned as they eat their way out of the host. Soil dwellers are more susceptible to soil drenches, while leaf dwellers are more vulnerable to sprays (Matteoni *et al.* 1993).

The effect of chemical pesticides on natural enemies also depends on the type of pesticide used. Broad-spectrum insecticides adversely affect more natural enemies than selective ones. Systemic insecticides have a longer residual effect than non-systemic. Most

fungicides are compatible with biological control programmes, except benzimidazoles (e.g. benomyl, cardendazim, and thiophanate methyl) which adversely affect the egg laying ability of predatory mites (Matteoni *et al.* 1993), and pyrazofos and triforine because their LD₅₀ are at the same level as the current recommended dosage (van der Staay 1991). All wetting agents, excluding Epsom salts, are toxic. Enstar (kinoprene), an insect growth regulator recommended for control of whiteflies and aphids, and Vendex (fenbutatin oxide), a miticide, are the only chemical pesticides safe for use in coordination with onion thrips natural enemies (*Amblyseius*, *Orius*, and *Hypoaspis* spp.). Others have an intermediate effect or a harmful period associated with their use (Matteoni *et al.* 1993).

Currently there are no selective insecticides against thrips. The future of chemical involvement in thrips control lies in a change from invertebrate poisons targeting all arthropods to synthetic analogues of pheromones, allomones and kairomones. The development and implementation of biorational agents insecticides requires thorough knowledge of the tritrophic relationship between the plants, the herbivores, and the beneficials. Antifeedants or invertebrate alarm pheromones offer the most potential (Jacobson 1997).

2. Predatory Mites

ABSTRACT

An experiment was conducted to determine and compare the predation rate of the gravid females of two predatory mites, *Amblyseius cucumeris* (Oudemans) and *Iphiseius* (= *Amblyseius*) *degenerans* (Berlese) [Acarina: Phytoseiidae] on first and second instar onion thrips, *Thrips tabaci* Lindeman [Thysanoptera: Thripidae], larvae on leaf disc arenas. Over 3 days, mites were removed from their food source and placed individually on an arena containing a 20 mm cucumber leaf disc cucumber cv 'Jessica'. Gravid females were identified by the presence of an egg after the 24 hour period. For each mite species, one gravid female was placed on an arena with either six teneral first instar larvae less than 24 hours old, or six second instar larvae less than 24 hours after eclosion. Experiments were arranged in a completely randomized design with 15 replications and placed in an controlled environment chamber maintained at $26^{\circ}\text{C} \pm 1^{\circ}\text{C}$ with a 16L:8D photophase:scotophase. The number of larvae consumed over a 24 hour period was recorded and analysed using ANOVA. Significantly more first instar thrips (3.6 ± 1.13) than second instar thrips (3.4 ± 0.81) were preyed upon by the gravid female mites. There was no significant difference between the predation rate of *A. cucumeris* or *I. degenerans* for either first or second thrips larval instars suggesting that these mites have an equal potential to control onion thrips in greenhouse cucumbers.

2.1 Background

There have been successes and failures with the introduction of predatory mites in greenhouses in different countries. The rate of success has been lower on cucumbers than on peppers, lower for *Frankliniella occidentalis* than *Thrips tabaci*, and soilless cultures (e.g. hydroponics, nutrient film technique) have more problems than traditional or natural soil ones (Ruidavets 1995). In Canada, Gilkeson *et al.* (1990) reported that *A. cucumeris* successfully controlled *T. tabaci* on greenhouse cucumbers, sweet peppers, and chrysanthemums. The onion thrips, however, have been reported to escape these predators and reach epidemic levels in greenhouse cucumber production in Nova Scotia (Stokdijk¹, pers. comm.), England, and British Columbia (Elliott², pers. comm.).

Many factors, particularly environmental factors, affect predator efficiency. Temperature has an obvious influence because mites are poikilotherms. Consequently, environmental temperature determines the kinetics of biochemical reactions in the mites' physiology (Sabelis 1985). The effects of temperature and relative humidity on the development of *A. cucumeris* were studied by van Houten and van Lier (1995). At a constant relative humidity of 80 percent, mean development time of *A. cucumeris* eggs decreased from 4.0, 2.4 and 1.8 days at temperatures of 20°, 25°, and 30°C, respectively. The saturation deficit at which only 50 percent of eggs hatch (SD_{50}) increased as temperature increased. The critical relative humidity for egg survival was approximately the same at all temperatures tested. In a greenhouse experiment almost all eggs of *A. cucumeris* survived at a relative

¹Stokdijk, P.: Stokdijk Greenhouses, Beaverbrook, Nova Scotia.

²Elliott, D.: Applied Bionomics, Sydney, British Columbia.

humidity of 45 percent.

The influence of VPD (vapour pressure deficit) on the rate of predation by *A. cucumeris* on *Frankliniella occidentalis* was also determined in the laboratory by Shipp *et al.* (1996). At a constant temperature, the rate of predation decreased with increasing VPD between 1.24 to 1.44 kPa. Above these, the rate of predation started to increase again. At constant VPD, the rate of predation slightly decreased at lower temperatures and increased at higher temperatures. The optimal conditions for maximum predation for *A. cucumeris* on first instar nymphs of *F. occidentalis* was 0.75 kPa. For greenhouse cucumber crops, the recommended production temperatures and VPDs are 17° to 25°C and 1.5 kPa.

On parthenocarp cucumbers success has been more variable due to the limited availability of pollen in the crop as an alternative food source for predatory mites during periods of low prey densities (Gilkeson *et al.* 1990). There is conflicting evidence about the effect of pollen on predation by *A. cucumeris*. van Rijn and Sabelis (1993) studied pollen as an alternative food source for *A. cucumeris* on cucumber leaves. Development and reproduction of the predator was enhanced but predation rate was decreased. Experiments by van Houten and van Stratum (1995) indicated when both pollen and thrips larvae were available, *A. cucumeris* and *I. degenerans* feed on thrips larvae in lieu of pollen. If alternative food sources adversely affect predation, they may, however, prevent predators emigrating during periods of low prey density. Spraying suspensions of bee-collected pollen on cucumber plants facilitated the establishment of *A. degenerans* and allowed it to reproduce in the absence of prey maintaining isolated predator colonies for about one month with 0.5 g pollen•colony⁻¹ (Ramakers *et al.* 1989). Thrips larvae also feed on pollen and this may

shorten the developmental phase in which they are vulnerable to attack by predatory mites (van Rijn and Sabelis 1997). Availability of suitable prey is dependent on the dynamics of the age structure of the prey population. Upon contact with a starved predator, second stage onion thrips larvae incurred a lower death risk than first stage larvae (Bakker and Sabelis 1989). The larvae of onion thrips reduced the attack success of their predators by jerking the abdomen and by producing a drop of rectal fluid. After contact with the sticky faecal droplets, individuals of *A. cucumeris* usually withdrew and cleaned themselves. When contacted on the thorax region, the jerking and faecal droplet defence was ineffective (Bakker and Sabelis 1989). In another study with *A. cucumeris*, in which both thrips first and second larval stages were anaesthetized, the difference in capture:success ratio, *i.e.* when prey is in fact consumed, was unchanged (Bakker and Sabelis 1989). This may be due to physical characteristics such as cuticle toughness or food quality.

In laboratory studies, predation rate and oviposition rate for *I. degenerans* were lower than *A. cucumeris* on a diet of western flower thrips larvae. At 25°C and 70 percent humidity, *A. cucumeris* killed 6.0 first instar larvae per day and had a mean daily oviposition rate of 2.2 eggs, while *I. degenerans* had a predation rate of 4.4 larvae per day and laid only 1.4 eggs daily (van Houten *et al.* 1995). In sweet pepper crops, *I. degenerans* displaced *A. cucumeris* within 13 weeks and was found on leaves and in flowers located on plants in rows where it was not released indicating better searching efficiency due to higher locomotory activity (van Houten and van Stratum 1995). In comparison to *A. cucumeris*, the eggs of *I. degenerans* were shown to be least sensitive to low air humidity. The females of *I. degenerans* showed total absence of diapause and intermediate levels of predation and

oviposition on both thrips larvae and pollen. *I. degenerans* is considered one of the most promising predators for biological control of thrips in greenhouses, particularly under conditions of low humidity and short day length (van Houten *et al.* 1995).

The objective of this experiment was to determine and compare the predation rate of the gravid females of these two predatory mites, *Amblyseius cucumeris* and *Iphiseius degenerans*, on first and second instar onion thrips larvae on greenhouse cucumbers.

2.2 Materials and Methods

2.2.1 Thrips source: Onion thrips were collected from several commercial onion (*Allium cepa*) fields in the Annapolis Valley area. Samples were sent to Agriculture and Agri-Food Canada³ for species identification and were confirmed to be *Thrips tabaci* Lindeman. The insects were reared on potted onions, leeks (*Allium porrum*), and cabbage (*Brassica oleracea*) in a controlled environment chamber⁴. The plants were maintained at $25 \pm 1^\circ\text{C}$ under supplemental fluorescent and incandescent lighting ($125 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) at 16L:8D photophase:scotophase and high humidity. The plants were fertilized once a week with a 200 ppm solution of chelated 20-20-20 plant growth fertilizer. Aphids on the cabbage were controlled with the specialist parasitic wasp, *Aphidius matricariae* [Hymenoptera: Aphidiidae].

³Footitt, R.: Eastern Cereal & Oilseed Research Centre, Agriculture & Agri-Food Canada, Ottawa, Ontario.

⁴Convion CMP 3023: Controlled Environments Ltd., Winnipeg, Manitoba.

Thrips used in the experiment were allowed to complete a minimum of two generations on cucumber leaf discs prior to experimentation. This was accomplished by placing five adult thrips on rearing arenas (described below) and allowed to oviposit for two days. The live thrips were then transferred to new arenas and dead ones were replaced with fresh ones from the rearing source. This procedure was repeated on alternate days over a period of several weeks prior to and during the experiments to maintain the availability of necessary populations. Those larvae not used in experimentation were allowed to reach adulthood to maintain the rearing process.

2.2.2 Plant material propagation: Parthenocarp cucumber plants, *Cucumis sativus* cv. Jessica, were grown under similar conditions as the rearing plants. They were seeded in rockwool propagation blocks and maintained in a 200 ppm 20-20-20 plant growth fertilizer nutrient solution. Micronutrient deficiencies were corrected with two foliar sprays ten days apart of 30 g·100 L⁻¹ chelated micronutrient mix. The plants remained pest and disease free for the duration of the experiment and required no further treatments.

2.2.3 Experimental arenas: A modified leaf disc method developed by Brodeur and Cloutier (1992) was used for the experimental arenas. The arenas were constructed from 28 mL clear plastic cups with lids. A 23 mm circular piece was burned from the base of the cup and the holes were covered with nitex nylon screen (188 µm mesh size) stuck with double sided tape. The seam between the cup and the screen was sealed with melted paraffin wax. The cups were inverted so that the lids served as the base. The shape of the lid provided a raised well which was surface sterilized under ultraviolet light for 20 minutes and then filled

with 3.5 mL fertilized agar. This agar was made by adding 8 g·L⁻¹ agarose⁵ to a solution of 20-20-20 plant growth fertilizer formulated at a rate of 2 g·L⁻¹ distilled water. The mixture was autoclaved⁶ for 20 minutes at 121 °C and 106 kPa. The agar was incubated⁷ at 45 °C until used. Immediately prior to use, a fungicide solution was added at a rate of 1 mL·L⁻¹ fertilized agar. The fungicide solution consisted of 0.3 g a.i. benomyl⁸ [methyl 1-(butylcarbamoyl)-2-benzimidazole carbamate], 7 mL 100 percent ethanol⁹, and 3 mL distilled water. To accommodate thrips' thigmotactic behaviour, leaf discs measuring 20 mm in diameter were cut along the main veins of mature, middle aged leaves. Prior to being placed on the agar, the leaf discs were dipped for approximately three seconds in a 3 mL·L⁻¹ bleach¹⁰ (commercial 5.25 percent hypochlorite concentrate) solution and 3 seconds in distilled water. The moat surrounding the raised well was filled with distilled water. This water was multi-purpose: it provided a water source for the mites, prevented complete escape of mites and larvae from the arenas, and maintained high humidity within the arenas. The arenas were assembled within a laminar flow cabinet¹¹ and placed in clear containers measuring 32.0 cm x 25.5 cm x 9.5 cm which were sprayed with 70 percent ethanol prior to use. The bottom

⁵Agarose: Becton Dickenson & Co., Cockeysville, Maryland.

⁶Steromaster Mk II SSR-3A: Consolidated Stills & Sterilizers, Boston, Massachusetts.

⁷Imperial II: Lab-Line Instruments Inc. Designers & Manufacturers, Melrose Park, Illinois.

⁸Benlate[®] 50WP: Du Pont Inc. Agricultural Products, Mississauga, Ontario.

⁹Commercial Alcohols Inc., Boucherville, Quebec.

¹⁰Javex[®]: Colgate-Palmolive Canada Inc., Toronto, Ontario.

¹¹Laminar flow cabinet CF72: Western Scientific Services Ltd. Richmond, British Columbia.

was lined with paper towel moistened with distilled water to prevent the arenas from desiccating.

2.2.4 Predatory mites source: Two species of predatory mites, *Amblyseius cucumeris* and *Iphiseius degenerans*, were acquired from a Canadian supplier¹². Over three days, 30 adult mites were removed from their container and food source daily and placed individually on an arena and starved for 24 hours. Only gravid females were used in the experiments because they are the most effective predator stage. Gravid females were identified by the presence of an egg on the arena after 24 hours.

2.2.5 Predation experiments: For each species of mite, one gravid female was placed individually on an arena with either six teneral first instar larvae less than 24 hours old, or six second instar larvae less than 24 hours after eclosion. Arenas were arranged in a completely randomized design, with treatments replicated five times each over three days (a total of 15 replications). Containers holding the arenas were placed in an environmental chamber¹³ and maintained at 26 ± 1 °C with fluorescent and incandescent supplemental lighting $95 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with 16L:8D photophase:scotophase. The number of larvae consumed over a 24 hour period was recorded. This was determined by considering both the number of shrivelled thrips masses and the number of remaining whole live larvae.

¹²Koppert Canada Ltd., Scarborough, Ontario.

¹³Biotronette Mark III: Lab-Line Instruments Inc. Designers & Manufacturers, Melrose Park, Illinois.

2.2.6 Statistical analysis: Final data were subjected to analysis of variance (ANOVA) using the general linear model procedure of SAS¹⁴. Examination of the residuals showed them to be normally distributed with constant variance. Significant differences between treatment means were determined using p-values from analysis of variance. P-values <0.01 were considered highly significant, ≥ 0.01 and ≤ 0.05 were considered marginally significant, and >0.05 were not significant.

2.3 Results and Discussion

There was no significant difference between the rate of predation of the two predatory mite species tested ($p=0.2482$). This corresponds with findings by Bakker and Sabelis (1989) in which *A. cucumeris* and *I. degenerans* had equal abilities to successfully attack *T. tabaci*. In studies performed by van Houten *et al.* (1995) *A. cucumeris* had a higher predation rate than *I. degenerans* on first instar western flower thrips larvae. When preying on larvae in the laboratory, attack success depended on size of the prey, feeding state of the predator, and diet of the predator (van der Hoeven and van Rijn 1990). Caution must be employed, however, when interpreting differential attack success of predatory mites. *A. cucumeris* reared on broad bean pollen had a higher capture:success ratio on thrips larvae when first removed from its food source, but decreased after successive feeds (van der Hoeven and van Rijn 1990). *A. cucumeris* are transported in controlled release system packages with a bran mite as their food source, while *I. degenerans* are often transported with pollen as their food source. By removing the mites from their respective food sources and not rearing them on onion thrips

¹⁴Statistical Analysis System, SAS Institute, Cary, North Carolina.

larvae prior to experimentation, the capture:success ratio may be influenced by an attempt of the mites to counterbalance a nutritional deficiency acquired from feeding on an alternative food source (van der Hoeven and van Rijn 1990). These results do indicate, however, the state of the predator after transport and the initial effect the predator may have on the thrips population in the greenhouse.

Significantly more first instar thrips were preyed upon by the gravid females than second instar ($p=0.0001$) (Table 1). There was no significant interaction between predatory mite species and larval instar ($p=0.6456$). Sabelis (1992) suggested that relative body size is the key in predator-prey dynamics, however, Bakker and Sabelis (1986) suggested an alternative explanation. *A. cucumeris* and *A. barkeri* were more successful with first instar thrips larvae than second instar larvae. When both larval stages were anaesthetized, the difference in capture:success ratio of the two larval instars was not changed. Physical characteristics such as cuticle toughness or food quality may be a serious contributing factor (Bakker and Sabelis 1986).

Table 1. Predation rate of predatory mites on *T. tabaci* first and second larval instars on cucumber leaf discs.

Life Stage	Mean predation \pm S.E.M
First larval instar	3.60 \pm 0.207
Second larval instar	3.37 \pm 0.148

2.4 Recommendations and Future Research

This study suggests there is no difference between the potential predatory effectiveness of *A. cucumeris* and *I. degenerans* on greenhouse cucumbers in the laboratory.

The true predatory effectiveness remains to be proven by testing both predators in the environment in which they are to control the pest - parthenocarp greenhouse cucumbers. An attempt was made to test these species in the research greenhouses; however, a sudden and unexpected decrease in the thrips population occurred which nullified the attempt.

In the greenhouse environment, the effect of the predator on the pest population takes into account important factors which identify effective biocontrol agents. The predator must have the searching capacity or dispersal powers (distribution in relation to prey) to locate prey even when they are rare. The searching ability of *I. degenerans* in sweet peppers was also found to be greater than *A. cucumeris* (van Houten and van Stratum 1995). This has yet to be proven in greenhouse cucumbers. Ramakers *et al.* (1989) maintained *I. degenerans* colonies in parthenocarp greenhouse cucumbers with pollen but did not determine their dispersal or predatory abilities when thrips larvae became available for prey.

The specificity of the predator to the prey is important for two obvious reasons. First, the introduced predator must not become a pest itself on the crop in which it is to exhibit control of other pests. Second, the predators must show minimal prey tendencies on other beneficials present in the natural enemy complex developed in the greenhouse or intraguild predation. This type of predation occurs when different predators are introduced to control the same pest (prey) and compete for the same food source and may prey on each other (Sabelis and van Rijn 1997). It is not necessary for the predator to be highly specific, but it must show a distinct preference for their prey, yet be able to survive on alternative food sources when the prey is rare, usually at the order or family level (*e.g.* onion thrips or western flower thrips - Thysanoptera: Thripidae). The predation rate of *I. degenerans* has also been

tested on spider mites (Yao and Chant 1989) and pollen (Ramakers 1995; van Houten and van Stratum 1995). It can survive and reproduce on both food sources. As mentioned above, the true effect of pollen on the overall performance of either *A. cucumeris* or *I. degenerans* remains in question.

The predator must have the power to increase in number, *i.e.* the intrinsic rate of natural increase (r_m) must be at least as rapid as that of the pest. This represents important economic information for greenhouse producers. Current recommendations comprise of regular applications of *A. cucumeris* in slow release packages to maintain predator levels. In recent years, the research has shifted from testing predator effectiveness on *T. tabaci* to *F. occidentalis* because the latter has surpassed the former in pest status in greenhouse vegetable production. Consequently, recommendations are currently based on this information. Bakker and Sabelis (1989) found that *A. cucumeris* and *I. degenerans* had equal ability to successfully attack *T. tabaci*. Lower oviposition rates have been found for *I. degenerans* than *A. cucumeris* on western flower thrips larvae in the laboratory (van Houten and van Stratum 1995). Castagnoli *et al.* (1990) found that *A. cucumeris* not only consumed more larvae per day on a diet of *T. tabaci* (5.41) than *F. occidentalis* (3.24), but also laid more eggs, 2.00 and 1.88 eggs per day, respectively. Such information indicates a possible distinction in versatility of the predators, *e.g.* a particular predator may be more effective on one particular thrips species than the other. This variation in population dynamics of the predator may also suggest a reassessment of the effects of both *I. degenerans* and *A. cucumeris* on the control of *T. tabaci* in parthenocarp cucumber production.

This study has shown that both predators have similar potential to control *T. tabaci* on cucumber leaf discs. More studies must be conducted to determine if *I. degenerans* is more efficacious against *T. tabaci* in a greenhouse cucumber production environment than *A. cucumeris*. The degree of mortality produced should be designed to prevent peak populations that will cause economic loss, e.g. 80 percent mortality as opposed 98 percent may be sufficient to achieve this (De Bach and Rosen 1991). Meanwhile, producers can continue to release either predator depending on availability and/or cost. Ultimately, producers could rear *I. degenerans* on pollen, e.g. castor bean plants (*Ricinus communis*) within their greenhouses and distribute it as necessary (Stokdijk¹⁵, pers. comm.)

¹⁵Peter Stokdijk: Stokdijk Greenhouses, Beaverbrook Nova Scotia.

3. Scented Traps

ABSTRACT

The effect of the addition of the volatile chemical attractants, *p*-anisaldehyde (4-methoxybenzaldehyde) and ethyl nicotinate (3-pyridinecarboxylic acid), to commercially available blue and yellow sticky traps was examined for adult onion thrips, *Thrips tabaci* Lindeman [Thysanoptera: Thripidae], in greenhouse cucumber production. Blue and yellow sticky traps were baited with 50 μ L of each scent in a slow release dispenser and placed 10 cm above the crop canopy perpendicular to the rows and their daily captures were recorded. Two studies were conducted at separate locations: a commercial cucumber greenhouse and two research greenhouses.

There was no interaction between scent and colour at the commercial site. Anisaldehyde significantly increased captures by a factor of 1.7 over ethyl nicotinate and 1.2 times more than the control. Ethyl nicotinate did not increase captures over the control. Blue sticky traps caught twice as many thrips than yellow traps, and yellow caught 5.0 times more than clear. This indicates that blue is the colour of choice for capturing adult onion thrips in greenhouse cucumber production. In the research greenhouses, there was a significant interaction between ethyl nicotinate and yellow traps. This combination caught 1.6 times as many thrips as the next most attractive combination, non-baited blue traps. The factors and thrips behavioural mechanisms for host-finding cues affecting these different results between locations are discussed.

Correlations between captures by the non-baited traps at the commercial site and the numbers of thrips per leaves were investigated to determine if adult thrips captures on sticky

traps were indicative of infestation levels on the leaves. There was no correlation between either blue or yellow sticky traps, and a moderate correlation between clear trap captures and captures on leaf samples. Consequently coloured traps seem to concentrate thrips in their vicinity. Captures of *Orius* predators on sticky traps were also examined. Scent did not increase captures of these predators on sticky traps. As reflected in the thrips results, blue sticky traps were 1.4 times more attractive than yellow and 15.0 times more than clear, indicating captures were not incidental, however biological control agents may also be susceptible to cues similar to those of their prey, especially to yellow hues in general. In this study a specific predator (*Orius* sp.) was more attracted to a blue hue.

3.1 Background

Although coloured sticky traps catch and kill adult thrips, the overall reduction in the population is not significant (Teulon and Ramakers 1990). Sticky traps may not be effective during flowering or fruit ripening because thrips may be more attracted to these plant structures than the traps (Frey *et al.* 1994). Vision and olfaction are the primary cues used by insects to orient to plant and floral hosts and sometimes these two cues work in concert (Dobson 1994). Consequently, control using sticky traps could be enhanced by the addition of an attractant. Addition of volatile chemicals can be useful in two ways: 1) it may aid in the determination of initial occurrence of thrips; 2) traps with volatile chemicals may be useful for control by trapping thrips where wind or air movement does not preclude the movement of thrips towards traps and does not quickly disperse volatiles (Teulon *et al.* 1993).

Several volatile chemicals have been tested to improve sticky trap captures. Aldehydes were the first floral scents shown to attract thrips (Howlett 1914) and currently show the most potential for attracting thrips (Teulon and Ramakers 1990). Anisaldehyde (4-methoxybenzaldehyde), a flower scent and a metabolite of certain wood rotting fungi, has been shown to be a strong thrips attractant (Kirk 1985; Brødsgaard 1990, Teulon and Ramakers 1990). Teulon *et al.* (1993) found that anisaldehyde baited traps attracted one hundred times more *T. tabaci* than non-baited traps. Other thrips species are associated with ripe fruits or vegetative hosts, therefore a non-floral olfactory cue may be used to detect them (Terry 1997). Ethyl nicotinate (3-pyridinecarboxylic acid) has been found in low concentrations in the fruit of carambola (*Averrhoa carambola*), but has not been reported in other foods (Wilson *et al.* 1985) and does not appear to be a constituent in floral fragrances (Teulon *et al.* 1993). Ethyl nicotinate was shown to increase captures of *Thrips obscuratus* by one hundred times as well as capturing thrips two weeks earlier than non-baited traps. Attraction of *T. tabaci* was increased by a factor two to five times (Penman *et al.* 1982).

The behavioural mechanism responsible for these results remains controversial. Observations in flight chamber studies by Hollister *et al.* (1995) suggest a chemokinetic (undirected) response of western flower thrips to ρ -anisaldehyde. Thrips use scents more efficiently as an arrestant or to stimulate a visual response than for anemotaxes (Kirk 1985). Several researchers support odour-induced visual response as the most probable orientation response involved (Kirk 1987; Brødsgaard 1990; Teulon and Ramakers 1990). It is unclear whether host finding cues of flower and fruit dwellers, such as *Frankliniella* species, are the same as leaf dwellers such as the onion thrips. When determined, it could be possible to

exploit this response to prevent infestation or spread (Kirk 1985).

The success of volatile chemicals in trapping depends on several factors. Odour attractiveness usually shows a concentration related optimum above which compounds that usually attract insects exert repellency (Frey *et al.* 1994). Kirk (1987) showed that the presence of scent represented a smaller factor of increase of the trap catches for large traps compared to small ones, thus a high visual apparency could reduce the effect of scent. Brødsgaard (1990) suggested that if a strong visual apparency decreases the effect of scent, a smaller trap or sub-optimal colour may improve effectiveness. Appropriate dispensing of the attractant is also critical. In another study, painting the chemical directly on the trap resulted in higher catches than using an impregnated filter paper wick (Teulon *et al.* 1993). Trapping efficiency is a consequence of the release rate of the chemical; therefore, a slow release dispenser may offer an effective alternative. The purpose of this study was to determine if volatile attractants can significantly increase thrips captures on commercially available sticky traps and assess their potential for use for mass trapping.

3.2 Materials and Methods

3.2.1 Greenhouse facilities: Commercial greenhouses (Stokdijk): There were two crops considered in 1997 in this greenhouse. The first was established in one half of the greenhouse in mid-April and the second one was located in the other half by mid-May. Total plant density was approximately 5000 plants per 3500 m² (1.43 plants·m⁻²). A section measuring 22.2 m x 19.2 m was used for experimentation in each crop. The plants were grown hydroponically

according to Grodania¹⁶ recommendations with greenhouse specific adjustments for the crop. The plants were trained in a modified v-system umbrella and maintained under standard production regimes of nutrient and controlled climate. Thrips were controlled using regular releases of the predatory mite *A. cucumeris*. During periods of peak densities, these predators were supplemented with *I. degenerans* and the minute pirate bug *O. insidiosus* [Hemiptera: Anthocoridae]. Other pests were controlled as necessary with their respective biological control agents: whiteflies - *Encarsia formosa* [Hymenoptera: Aphelinidae], fungus gnats - *Hypoaspis miles* [Acari: Laelapidae], and spider mites - *Phytoseiulus persimilis* [Acari: Phytoseiidae].

Research greenhouses (Harlow): Two research greenhouses were used, each measuring 15.2 m x 9.6 m. Both were under plastic and were attached to a common header house. Plants were grown in a modified nutrient film technique developed by Cooper¹⁷ and modified by Toms¹⁸, and maintained at standard production regimes of nutrition and controlled climate and trained in a modified umbrella system.

The summer 1996 cucumber crop was not considered because thrips populations were extremely low in the greenhouses at this time. Regular inundations of several hundred thrips did not establish. The 1996 fall crop was seeded 30 July in a propagation house and moved into the greenhouse 9 August. There were six cucumber cultivars grown: Discover, E2413, Flamingo, Kalunga, LM819, and Tyria. These cultivars were arranged in plots of four plants

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