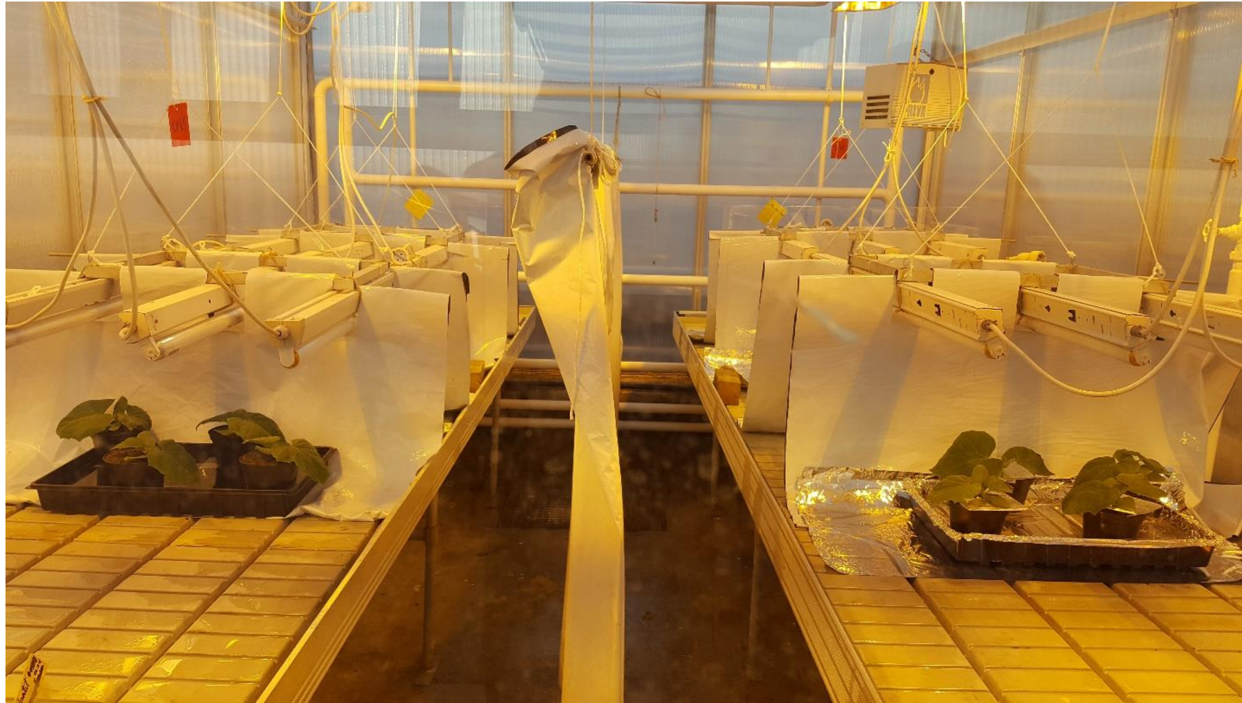
Norwegian University
of Life Sciences

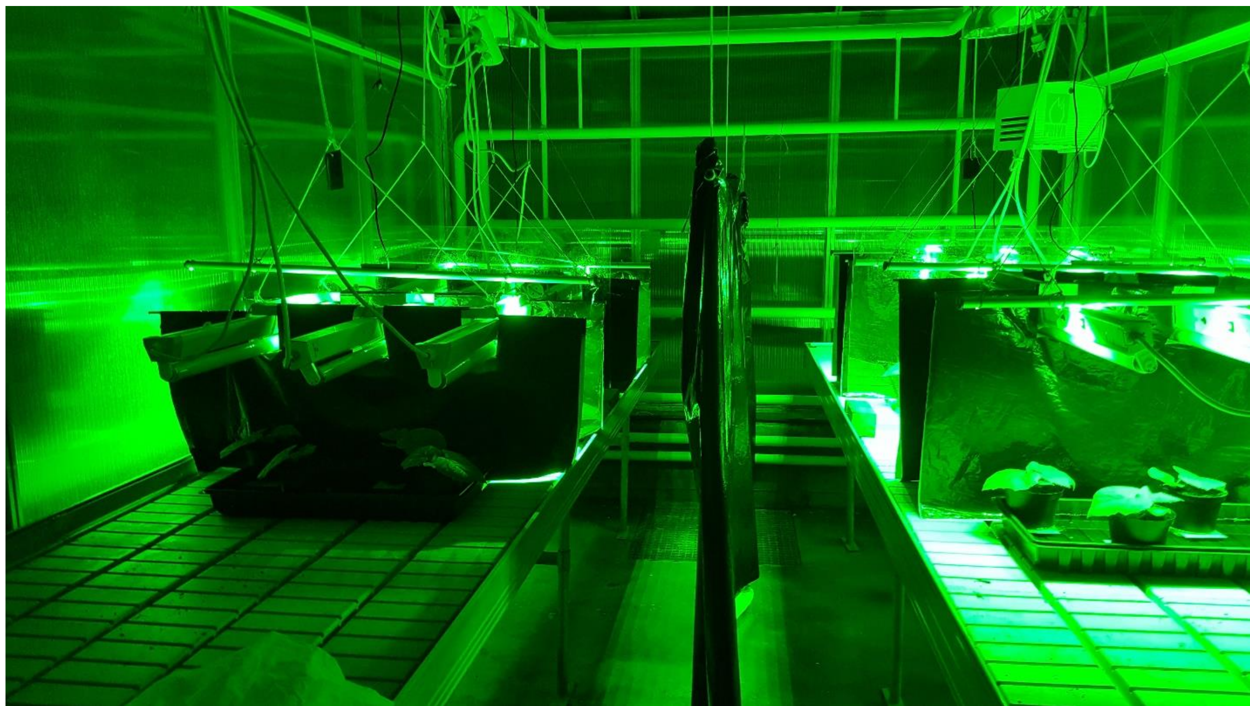
Master's Thesis 2017   60 ECTS
Institute of integrated pest management (IPM)
Nina Svae Johansen

Ultraviolet radiation as a tool to control *Tetranychus urticae* in greenhouse production

Carl Emil Øyri
Master thesis in Animal biology – Entomology

Ultraviolet radiation as a tool to control *Tetranychus urticae* in greenhouse production





Acknowledgments

I would like to express my deepest gratitude to my supervisor Nina Svae johansen for support and encouragement during the writing process. Also, I am thankful to my secondary supervisor Suthaparan Aruppilai for technical support and help with taking the light measurements.

Also, my appreciation goes to Karin Westrum "the mite lady" and Andrew Dobson for practical support in the process.

I am grateful to my family and friends for understanding why I have been so absent during the last year. Especial thanks go to Sabnam Mahat for comfort, food and being there. Thanks goes to my brother Audun and last but least my cat, for always loving me.

// Abstract

Tetranychus urticae Koch has an ubiquitous distribution, is remarkably polyphagous and is known to be the most acaricide resistant arthropod. This thesis examines how short wavelengths of ultraviolet radiation (UV) can be used to kill and suppress *T. urticae* populations in a greenhouse environment. *T. urticae* was exposed to three minutes of indirect UV (288 ± 36 J/m^2/day) every night for 14 and 21 days, using cucumber (*Cucumis sativus* 'Parka') as host plants. UV was administered in combination with both reflectors and Green LED light to increase the exposure mites received. Alive and dead individuals were counted and categorized into four life-stage groups (eggs, larvae, nymphs and adults). Mortality was most prolific when UV was combined with either reflectors or both reflectors and Green LEDs, UV alone or combined with Green LEDs were less effective at reducing *T. urticae* populations. The deleterious effects of UV affected all but the adult stage of *T. urticae*. Green LED light exposure did not have the intended positive phototaxis effect of luring mites to the axial side of leaves before UV treatment was initiated, but this may have been caused by the high intensity of the green light (17,11 ± 2,28 W/m^2) transmitting through the leaves.

Table of Contents

Acknowledgments 2
Abstract 3
Definitions and abbreviations 5
Introduction 1
Materials and methods 6
Rearing of plants and mites for experiments 6
Experimental conditions 6
Experimental design: 7
Plant setup: 8
UV-B in combination with reflector 9
Experiments including green light 12
Registration procedure 14
Statistics 17
Results 17
Experiment 1 17
Experiment 2 19
Experiment 3 20
Experiment 4 21
Experiment 5 22
Experiment 6 24
Comperative results 26
Temperature and relative humidity 34
Additional comments 34
Discussion 36
Conclusion 44
Bibliography 45
Appendices 49
Appendix 1 49
Appendix 2 52

Definitions and abbreviations

the Bunson-Roscoe law of reciprocity states that: “A certain biological effect is directly proportional to the total energy dose irrespective of the administered regime. Dose is the product of intensity and the duration of exposure and thus the time required to deliver a certain dose is influenced by the intensity of the source and whether the exposure is continuous or fractionated” (Schindl et al. 2011).

Ultraviolet (UV)

Reactive oxygen species (ROS)

Controlled environment agriculture (CEA)

Integrated pest management (IPM)

Relative humidity (RH)

Light emitting diode (LED)

Introduction

Tetranychus urticae is an economically important pest worldwide due to its ubiquitous distribution and wide range of host plants. At least 150 of these are economically important in agricultural crops, many of which are grown in greenhouses (Tehri 2014). The use of greenhouses in plant production has greatly extended the distribution range of *T. urticae,* not only because its reproductive potential is highly dependent of temperature, humidity and food availability (Jeppson et al. 1975), but also because the transfer of plants across large distances has helped introduce the pest to new areas. Commonly used methods to fight *T. urticae* are chemical, biological or cultural, or a combination of these. In 2011, the amount of money the European Union spent on synthetic acaricides to combat *T. urticae* is estimated to have exceeded 1 billion USD (Attia et al. 2013). The problem with using chemical acaricides to combat *T. urticae*, is its ability to develop resistance due to many specialized genome adaptions related to digestion, xenobiotic transport and multidrug resistance proteins (Grbić et al. 2011). Being haploid arrhenotokous, *T. urticae* can reproduce without fertilization, providing a single resistant female survivor with the ability to generate a new acaricide resistant population. Haplo-diploid gender determination coupled with a rapid development and high fecundity, has made *T. urticae* the arthropod with the highest known incidence of pesticide resistance known to date (Grbić et al. 2011). Chemical control of *T. urticae* often leads to the development of cross-resistance to similar chemicals or multi-resistance to different classes of pesticides, its novel genome enabling it to develop resistance to new pesticides within 2-4 years (Grbić et al. 2011). The number of active ingredients in pesticides that *T. urticae* has become resistant to so far, is 95 (Sato 2016). Consequently, the need for research in alternative methods of combating or reducing *T. urticae* populations is therefore urgently needed.

In recent years, a growing body of research on how to use light to affect pest populations has been published, providing evidence that different spectra of light have the potential to work both indirectly and directly on several types of arthropod pests (Johansen et al. 2011). Such indirect interactions include plant mediated effects in response to either elongated photoperiods or in response to light with different spectral distributions (Vänninen et al. 2010). Plants adapt to the light environment they are exposed to and can change morphologically and biochemically in response. Photomorphogenesis is exemplified by how different plants grown within greenhouses

in northern latitudes during winter are less exposed to UV radiation and, as a result, become more susceptible towards herbivores (de Kogel et al. 1997). Patterson et al. (1994) found that reduced light intensity could affect strawberry plants susceptibility to *T. urticae.* The effect that UV-B has on higher plants has commonly been regarded as negative, but this is not always the case (Wargent & Jordan 2013). The effects that UV-B have on plants is dependent on dosage (exposure duration and light intensity), plant species and the growth-stage the plant is in when being exposed (Vänninen et al. 2010). The gene expressions in plants which activate during UV-B exposure, have a high degree of overlap with those expressed during wounding or herbivory. UV-B induces a stress response in plants via reactive oxygen species (ROS), the same signaling molecules used to warn the plant of abiotic or biotic stresses (e.g. herbivory). Photomorphogenic changes may include changes in the composition of epicuticular waxes, thicker leaves, increased trichome density and sharpness (Vänninen et al. 2010). UV-B can cause photochemical changes in plants such as; increased nitrogen content, reduction in the amount of available carbohydrates and an increase in the amount of fiber (lignin, cellulose and hemicellulose). UV-B also induces the production of certain secondary chemicals not part of the regular herbivory response, such as increasing flavonoid and phenolic content. These compounds increase the plant's resistance to UV, while also having the added advantage of decreasing the digestibility of plants (Vänninen et al. 2010).

The larger the ratio between the surface area and the volume an organism has, the larger the quantity of UV-B is absorbed and the less able an organism will be able to repair the DNA damage sustained from UV-B radiation (Suzuki et al. 2009). For most heterotroph organisms, UV-B radiation is absorbed by pigments and coenzymes, these are then excited, causing them to transfer their energy to H_2O molecules, creating ROS (e.g. H_2O_2). These ROS then react and oxidize important cellular components, such as membranes, proteins, lipids and nucleic acids (Suzuki et al. 2009). There are two pathways most cells can use to repair such damage; photo-enzymatic - and excision repair. The photo enzymatic pathway repairs damaged DNA directly through photolyase, whereby the enzyme is excited by visible light (especially blue and green) and UV-A, using the energy to bind to DNA and reverse the damage done. Excision repair includes several possible pathways involving a large group of enzymes which remove and replace damaged DNA, invariably using ATP as an energy source (Murata & Osakabe 2014). Because daylight contains both visible light and UV-A, some of the damage caused by UV-B is

directly repaired in *T. urticae*. Murata and Osakabe (2014) found that the effect of photoreactivation was dose dependent, and that the damage *T. urticae* sustained from UV-B could not be repaired if exposure to visible or UV-A was delayed by ≥4 hours.

The effectiveness of using UV-B to combat powdery mildews in indoor growing systems have been well documented (Suthaparan 2010; Suthaparan et al. 2014; Suthaparan et al. 2016a; Suthaparan et al. 2016b). But if UV-B is to be implemented as an IPM tool commercially in indoor plant-production, more research is needed on how it affects all organisms (e.g. pests, plants and biocontrol agents) in such a system. Johansen et al. (2017) conducted experiments where *T. urticae* was directly exposed to UV (1.6 W/m^2) for 3 minutes each night over a period of six days. What they found was that all but the adult stage of *T. urticae* sustained 99-100% mortality. This demonstrated that if exposure is achieved, nighttime application of UV is lethal to all but adult forms of *T. urticae.*

There is evidence that UV-B can be an effective tool to either directly or indirectly combat fungi, insects, *T. urticae* or other phytophagous mites in indoor plant production (Mazza et al. 1999; Mazza et al. 2002; Ohtsuka 2009; Onzo et al. 2010; Suthaparan et al. 2014; Suthaparan et al. 2016b; Tachi & Osakabe 2012). By exposing the fungi or mite to UV-B at night, photo-enzymatic repair is hampered, the organism is unable to repair some the damaged sustained to its DNA. Suthaparan (2010) investigated the effectiveness of using UV-B to suppress *Podosphaera pannosa* on roses; comparing night-time exposure to daytime exposure, and pre-inoculation versus post-inoculation exposure. He found that night-time application was much more effective than day-time application. UV-B exposure prior to inoculation of *P. pannosa* had no significant effect compared to controls, which indicate that the suppression effect in his experiments did not occur indirectly through the host-plant, but rather that it was a direct effect of *P. pannosa* being exposed to UV-B.

Suthaparan et al. (2016b) recently tested if the Bunsen-Roscoe reciprocity law (BRL) applies when using night-time application of UV-B on *Podosphaera aphanis* and *Golovinomyces biocellatus*, inoculated on rosemary and strawberry, respectively. He found that BRL does seem to apply, that irrespective of the regime used to administer, either continuous or fractured exposure to UV, the biological effect was proportional to total energy dose (duration x intensity) received. Although there were mostly statistically insignificant differences between the different

UV treatments as long as the dose was the same, Suthaparan et al. (2016b) found that the most significant reduction in sporulation of funguses compared to untreated control was 1,6 W/m^2 (wavelength: 280-400 nm, λ peak at 313nm (figure 5)) for three minutes each night. Because a UV dosage of 1,6 W/m^2 for three minutes per night has been found to be the optimal dose for combating different strains of Mildew without causing significant phytotoxic effects in neither strawberry nor rosemary, it is also the dose used in these experiments to test the effectiveness of UV on *T. urticae* in cucumber. Murata and Osakabe (2013) tested if BRL applies to different life-stages of *T. urticae*, they found that in general, BRL does apply to all life-stages they tested (eggs, larvae, ecdysis and adults), but also that UV-B could prolong development time and even halt egg production at doses >50 KJ/m^2 (wavelength: 280-320nm, λ peak at 310 nm). There were minor differences in mortality thresholds for the life stages from egg to nymphs in relation to the cumulative doses, but generally the threshold sensitivity decreased from eggs to adults. Chrysalis stages usually exhibited similar vulnerability towards UV-B as the preceding phase, with teleiochrysalis showing the highest variance.

As long as the host plant is healthy and is not overcrowded, *T. urticae* individuals will usually live on the abaxial (bottom side of leaf) side of the leaves (Fasulo & Denmark 2000). *T. urticae* use their mouth stylets to suck out the cell contents of the spongy mesophyll and palisade parenchyma. Its adaption to live on the abaxial leaf surface has previously been thought to be owed to rain avoidance (Ohtsuka 2009; Suzuki et al. 2009), but living on the abaxial side of leaves has been proven to be an adaption to UV avoidance (Murata & Osakabe 2013; Murata & Osakabe 2014; Sakai & Osakabe 2010; Sudo & Osakabe 2011). Leaves absorb most of the UV in sunlight, usually transmitting wavelengths between 400- and 700 nm (Suzuki et al. 2013). Overwintering *T. urticae* develop an orange color and seek out sheltered environments (e.g the soil, detritus or underneath bark) in response to shorter photoperiods, lower temperatures, food quantity and quality. The orange color is due to the accumulation of carotenoids which halts development, stops metabolism, increases UV and cold tolerance etc. Diapausing females of *T. urticae* show negative phototaxis toward all types of UV radiation and have no preference towards visible light, although they have no increased mortality when exposed to UV-B (Suzuki et al. 2013). This is because carotenoids scavenge ROS, providing protection from UV-B (Suzuki et al. 2009).

The photoreceptors of non-diapausing *T. urticae* females peaks in the UV-A (375mμ) and green parts of the light spectrum (525 – 550 mμ) (Jeppson et al. 1975; Ohtsuka 2009). This has been proposed as a defense mechanism to avoid the harmful effects of UV-B radiation from sunlight (Sakai & Osakabe 2010). UV-A (375 nm) stimulates negative phototaxis in *T. urticae*, while visible and especially green light (525 nm) has the opposite effect and attracts the mite (Naegele et al. 1966). More recently, Suzuki et al. (2013) conducted experiments to test out the photo-orientation of *T. urticae* in a virtual field on a chequered plate of dark and light areas. They exposed non-diapausing and diapausing *T. urticae* individuals to different light specters for 10 minutes and found that the negative phototaxis to UV (UV-B λ_{max} 307 nm and UV-A λ_{max} 370 nm) radiation was consistent across both forms. When exposed to visible light (wavelengths: blue λ_{max} 466 nm, green λ_{max} 536 nm and red λ_{max} 653 nm) of $\geq$2.0 W m^{-2}, only non-diapausing individuals showed positive phototaxis, they also reaffirmed that *T. urticae*'s vision peaks in the green light section of visible light (525 – 550 nm), showing positive phototaxis towards green light down to light intensities of $\geq$0.2 W m^2 (Suzuki et al. 2013).

The purpose of these experiments was to investigate how the optimal UV dose used for combating mildews (Suthaparan et al. 2016b), affects *T. urticae* under indirect exposure using cucumber as a host plant. Six experiments were conducted to evaluate the effectiveness of using UV radiation as a tool to combat *T. urticae* and possible ways to increase exposure. The first three experiments investigated how a reflector could be used in combination with UV-B to increase exposure on the abaxial side of the leaves, while the fourth and fifth experiments tested if green light could be used as a "lure" to attract *T. urticae* individuals to the axial (top side of leaf) side of the leaf before exposing them to UV-B radiation. The last experiment retested the most successful treatment from previous experiments and included a treatment which included all variables (UV, reflector and green LEDs).

Materials and methods

Rearing of plants and mites for experiments

Tetranychus urticae were reared on cucumber *Cucumis sativus* 'Parka', in insect cage (size: 70x50x50 cm). The mites were gathered from *Aspidistra* in Son, Norway, in 2000 and have since been kept in a climatic chamber with a 16-hour photoperiod, artificial light (3 x 120 cm fluorescent tubes, Philips**,** TL-D 90 Graphica 36W 965) with a luminosity of 75-95 µmol/m^2/s measured at average height of plants, with an Apogee model MQ-200 sensor. Relative humidity (RH) was set to 60 % and the temperature has been a constant 22 ± 5 ^{o}C. The mites have been living on beans, strawberry and lastly cucumber. This strain of mites has not been exposed to daylight or UV-B since collection until initiation of experiments.

Cucumber, (*C. sativus* 'Parka') used for the UV-exposure experiments were grown in pots (8x8x8.5 cm) with peat ("Go' Jord", fertilized peat, contents: 90% white-moss and 10% fine sand) in a climate chamber with artificial light (3 x 120 cm fluorescent tubes, Philips**,** TL-D 90 Graphica 36W 965**)**. The photoperiod was 16 hours (from 06:00 to 22:00). The luminosity was 65-75 µmol/m^2/s at average leaf height, measured with an Apogee model MQ-200 light sensor. The temperature in the climatic chamber was continuously 22 ± 5 ^{o}C with a RH value of 70%.

Experimental conditions

The experiments with UV-B, reflector and green light were conducted in a greenhouse room (8 m^2) with day-light and supplementary growth light at the Centre for plant research in controlled climate (SKP, NMBU), Ås (59° 40' 4" N; 10° 46' 2" E). Six experiments were conducted between: 15.03.2017 – 04.11.2017. Artificial light was provided for 16 hours (06:00 – 22:00) with an equal number of High Pressure Sodium (HPS) (400 W, Lucalox, manufactured in Hungary) and high-pressure Mercury (HPM) (400 W, Philips, manufactured in Hungary. When incoming daylight radiation below 400 W/m^2, artificial growth lights would turn on. The temperature was set to 24 ^{o}C, but varied somewhat 22 ± 7 ^{o}C, RH was 65 ± 15 RH % (fogging when RH < 65 %). Luminosity was 185-220 µ mol m^{-2} s^{-1} measured 20 cm above tables surface with an Apogee model MQ-200 sensor. Temperature and moisture in the experiment room was continuously logged to ensure environmental consistency.

Experimental design:

In the experiment room, armatures with fluorescent UV-B lamps were hung from the ceiling and adjusted so that the luminosity measured 20 cm above the table surface in each treatment area (average height of the two true leaves of the cucumber plants) was equalized at 1,6 ± 0,2 W/m^2. UV-B impenetrable Plexiglas plates (ordered from LOG.no (no specifications are available)) were placed on each table-top to separate the two tables in the experiment-room into four "blocks" (block 1- 4 in figure 1). Polyethylene sheets (ordered from LOG.no (no specifications are available)) ("light impenetrable plastic" in figure 1) were hung in-between all treatments and a large sheet of Polyethylene was hung in the middle of the room to split the entire room in two (figure 1). In each experiment, each treatment had 3 replicate trays (each tray with 4 plants). Each plant had two true leaves, the first and second leaf (not including cotyledons) (figure 2).

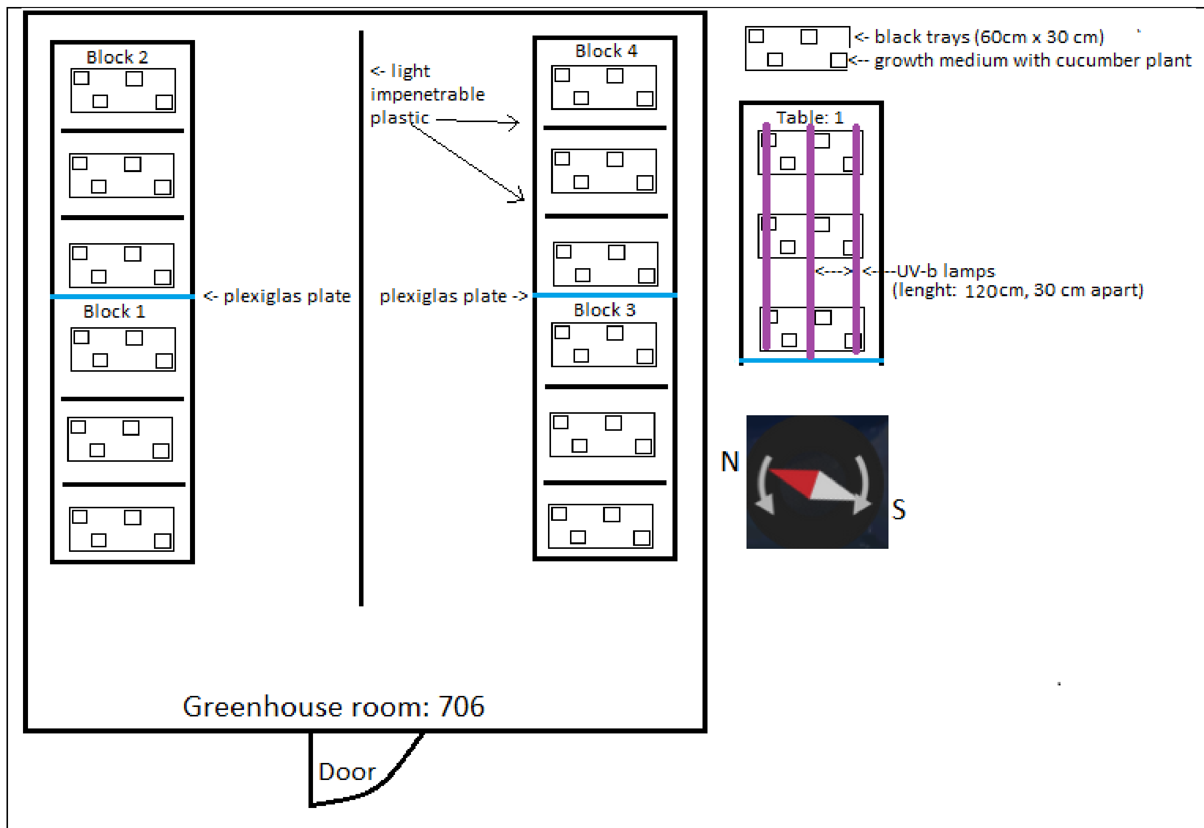


Figure 1. Room layout and experiment room setup (birds-view of room on left). Table 1 = How UV lamps were hung over each block).

Plant setup:

For each treatment section four plants were placed in a VEFI tray on top of small plastic boxes with an absorptive fiber-cloth underneath the pots. The Vefi trays were filled sufficiently with water to prevent T.urticae mites on the plants from escaping (figure 2). As leaves expanded to full size, the angle of the plants was adjusted to limit crossover of mites, both between plants and to the environment. 20 ± 3 day old, uniform sized cucumber plants with 2 true leaves each were used in the experiments. The plants were moved to the experiment room and left to acclimatize for 24 hours before each experiment started. The experiments began when each plant was infected with 12 newly molted adult female *T. urticae* (6 mites per leaf) and light timers for treatments were turned on. To make the selection and transfer of suitably aged female mites easier, a cucumber plant with 4-6 true leaves was placed in an established mite culture cage (71,5x51x51 cm) 5 ± 2 days before infection of leaf circles. One mite infected leaf circle (1.6 cm diameter) with 6 newly molted adult female mites (ca ≤40 hours since last molt) were placed abaxial side up on each of the true leaves axial side, of every experiment plant (in total 12 female mites per plant, 6 per leaf). The mites were left to walk from the leaf circles to the leaves of the experimental plants on their own.

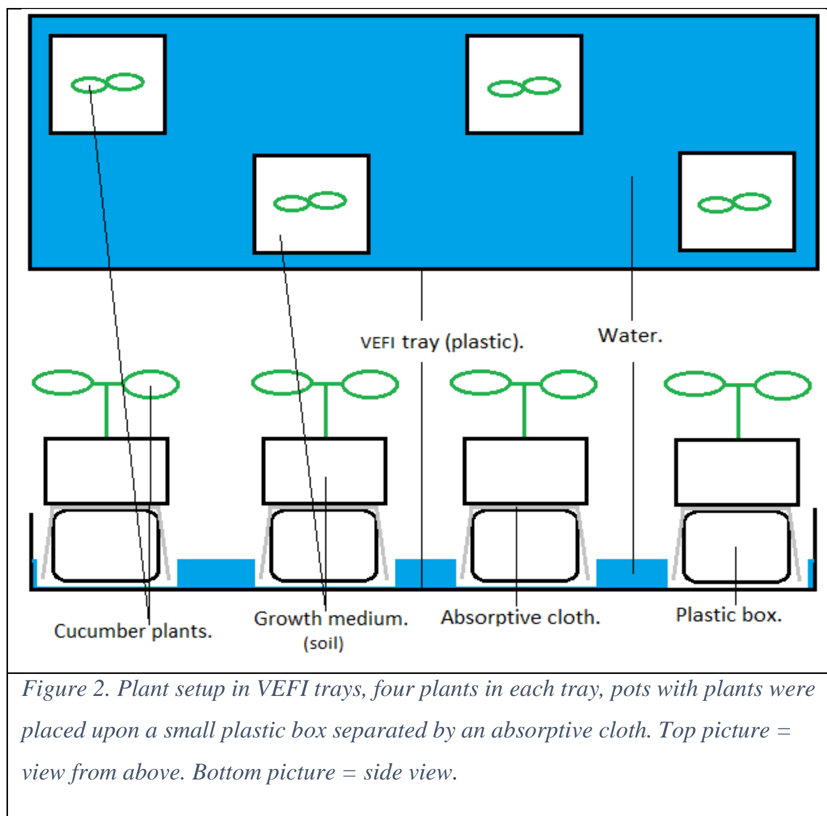


Figure 2. Plant setup in VEFI trays, four plants in each tray, pots with plants were placed upon a small plastic box separated by an absorptive cloth. Top picture = view from above. Bottom picture = side view.

In the first experiment, new leaves that would grow, were cut regularly and plants were given nutrient solution, resulting in stressed plants which might have been affected by nutrient accumulation. Therefore, all experiments that followed (EXP 2-6) were only cut once (32 ± 5 days after seeding) and were only given nutrient-free water (figure 20).

UV-B in combination with reflector

In the three first experiments conducted, UV exposure and the use of reflectors to increase exposure on the abaxial side of cucumber leaves were tested. The test variables were: reflector and ultraviolet radiation, Providing these 4 treatment combinations (figure 3 and 4):

1. Reflector combined with UV exposure
2. UV exposure
3. Reflector
4. Control (no UV, no reflector)

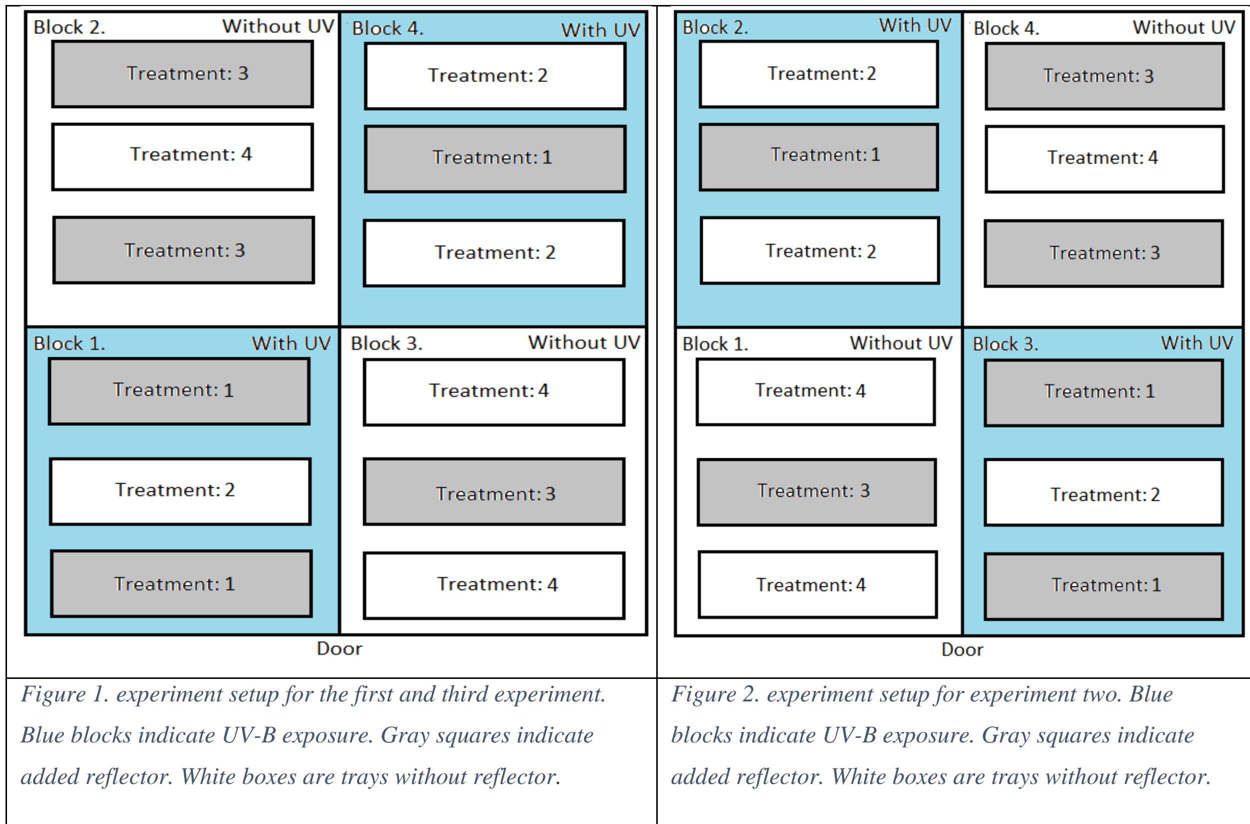
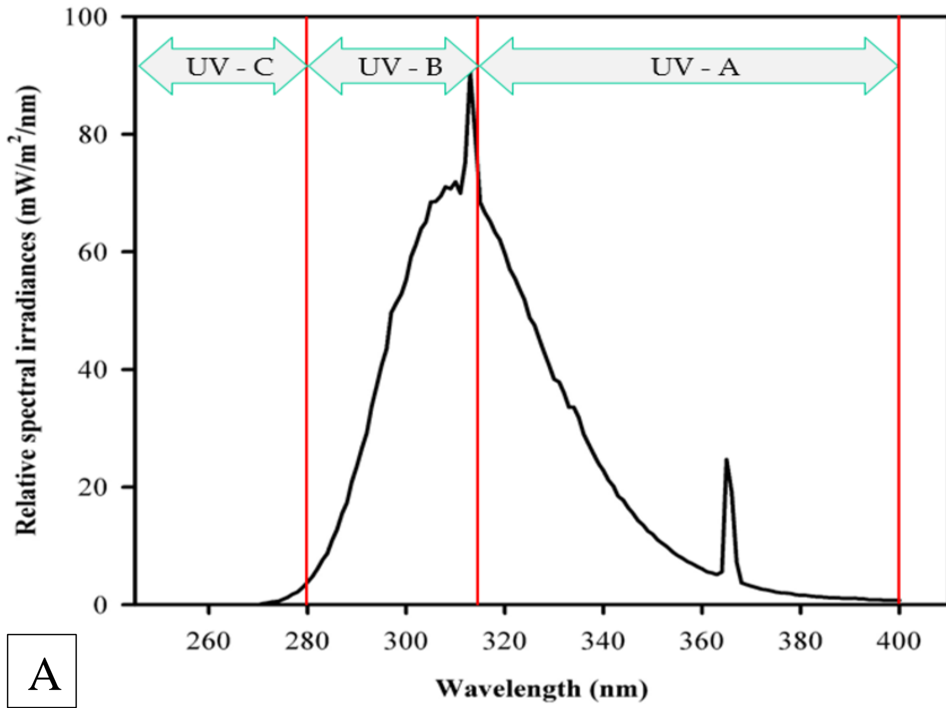


Figure 1. experiment setup for the first and third experiment. Blue blocks indicate UV-B exposure. Gray squares indicate added reflector. White boxes are trays without reflector.

Figure 2. experiment setup for experiment two. Blue blocks indicate UV-B exposure. Gray squares indicate added reflector. White boxes are trays without reflector.

Twelve lamps with 120 cm UV fluorescent tubes (model: UVB- 313 EL; Q-Panel Lab Products) were hung from the ceiling on armatures. Only 6 of the lamps were in use during each experiment, affecting half of the blocks (figure 1, 3 and 4). The remaining half of the UV lamps which were not active in each experiment, provided equal amounts of shading for all treatments. UV exposure started every evening throughout all the experiments; the lamps turned on at 23:15 and turned off again at 23:19 (1 min to heat-up, followed by 3 active minutes with UV radiation). The UV fluorescent tubes had a wavelength range of 280-400 with a λ peak at 313nm (figure 5 A). The intensity of the UV radiation was 1,6 ± 0,2 W/m^2 measured 20 cm above the table top (average height between the first and second true leaf of experiment plants). UV radiation as measured with an Optronic model 756 spectroradiometer light sensor (Optronic Laboratories, Orlando, FL, USA). This intensity of UV over a period of 3 minutes provide a daily dose of: 1.6 ± 0.2 W/m^2 → (1.6 ± 0.2 W/m^2)*180 s = 288 ± 36 J/m^2/day

Aluminum foil was used as a reflector in all experiments that included this variable. Aluminum foil was placed on top of the tables and inside Vefi trays. Reflector plates (12 x 12 cm) were made from cardboard covered in aluminum, these were then placed on top of pots underneath plants (figure 5 B). The aluminum foil used was a product originally intended for cooking, delivered by “Rio aluminum” (Ripadis B.V AS).



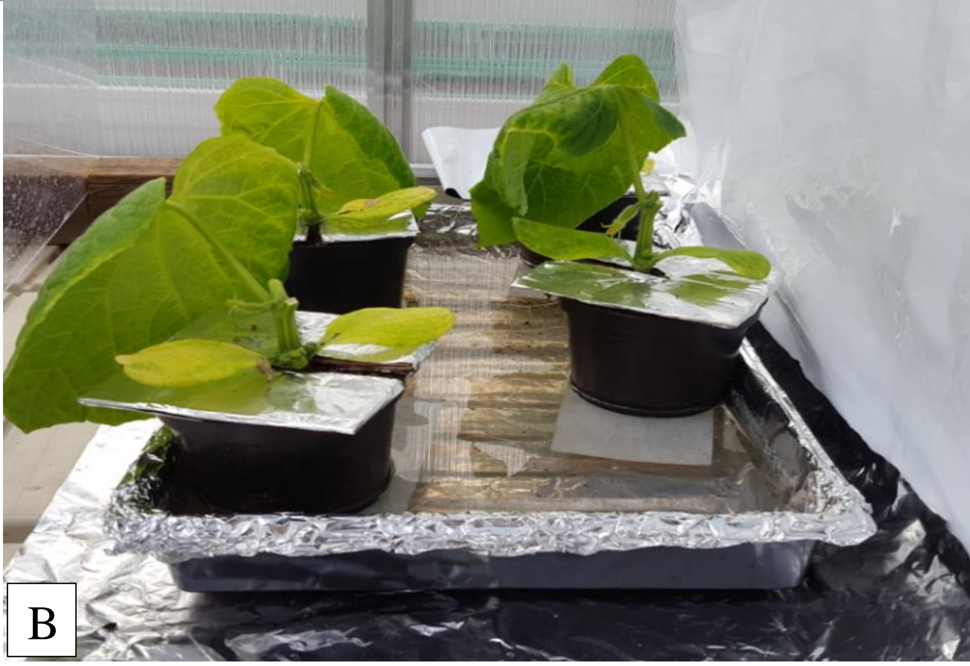


*Figure 5. Spectral distribution of the light from the UV lamps (*UVB- 313 EL; Q-Panel Lab Products*) used in all experiments* (A)*. How reflectors were set up* (B).

Experiments including green light

The second variable tested to increase UV exposure was green LEDs. In experiment 4 and 5, green LEDs were used both separately and in combination with UV (figure 6). The function of the green LEDs was to act as an attractant for the mites, luring them to the axial side of the leaves and thereby increasing their exposure to UV. In experiment 6, a treatment including all variables (UV, reflector and green LEDs) was added, the most effective treatment from experiment 1-3 was also retested (UV and reflector) (figure 7).

Providing these 4 treatments for experiment 4 and 5 (figure 6):

1. Green LED combined with UV-B exposure
2. UV exposure
3. Green LED
4. Control (no UV, no green LED)

While the treatments tested in experiment 6 were the following (figure 7):

1. Reflector combined with UV exposure
2. UV exposure combined with reflector and green LED
3. Green LED
4. Control (no UV, no reflector and no green LED)

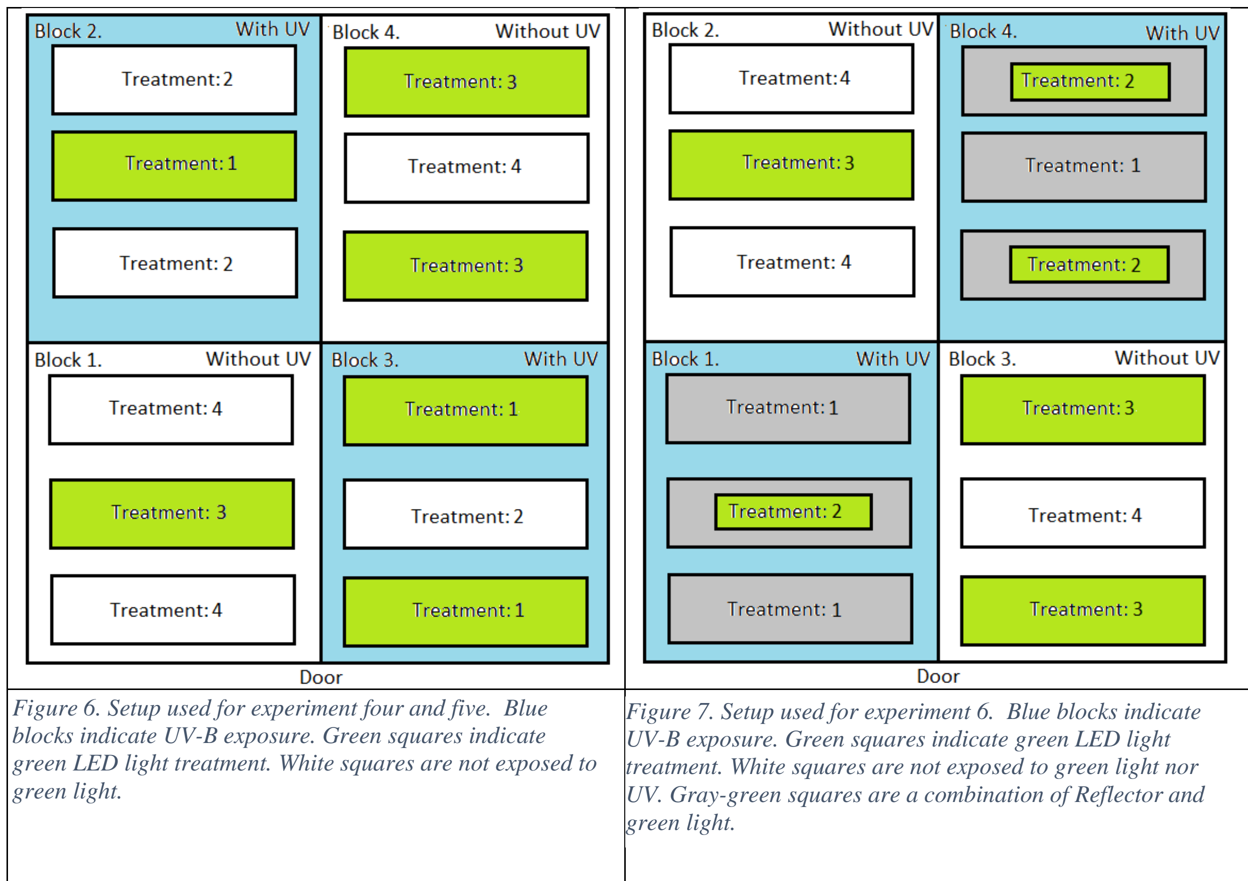


Figure 6. Setup used for experiment four and five. Blue blocks indicate UV-B exposure. Green squares indicate green LED light treatment. White squares are not exposed to green light.

Figure 7. Setup used for experiment 6. Blue blocks indicate UV-B exposure. Green squares indicate green LED light treatment. White squares are not exposed to green light nor UV. Gray-green squares are a combination of Reflector and green light.

A total of six green LED (RAY 44, Fluence Bioengineering, Texas, USA) lamps were hung above the UV-B lamps in six of the treatment plots, irradiating three trays with UV and three trays without UV (figure 6 and 7). The green LED lamps turned on 26 minutes before the UV lamps, and stayed on during the UV exposure (22:49 - 23:19), providing 30 active minutes of green light exposure. The reason the LEDs turned on 26 minutes before the UV-B lamps, was to allow the mites time to move from the abaxial to the axial side of the leaves. The lamps wavelength peaked at 525 nm and have an efficacy range from 1.2 – 2.5 µmol/J with a Photosynthetic photon flux (PFF) value of 105 – 185 µmol/s. The amount of radiation measured 20 cm above tabletop (average height between the two true-leaf's) was 75 ± 10 µmol/m^2/s. Green LED light was measured with a "LI-COR model LI-250 light meter"

Daily dose of green LED light was calculated using Planck's equation (E = hc/λ => (kinetic energy) = ((Planck's constant) x (speed of light)) / wavelength) to find the amount of joule in each photon and multiplying this by amount of photons/m^2/s.

$$E = (hc) \div \lambda = \left((6.63 * 10^{-36}\ \mathrm{Js}) * (3 * \ 10^{8}\ \mathrm{m\ s^{-1}})\right) \div 525\mathrm{nm}$$

$$= 3{,}789 * 10^{-19}\ \mathrm{J\ contained\ in\ each\ photon}$$

$$\rightarrow (75\ \pm\ 10) * 10^{-6}\ \mathrm{mol\ s^{-1}} * \mathrm{avogadros\ constant} =$$

$$> \left((75\ \pm\ 10) * 10^{-6}\ \mathrm{mol\ s^{-1}}\right) * (6.02\ \times\ 10^{23}\ \mathrm{quanta\ mol^{-1}})$$

$$= (4{,}515 \pm 6{,}02) * 10^{19}\ \mathrm{photons\ m^{-2}s^{-1}}$$

$$\rightarrow\ \left((4{,}515 \pm 6{,}02) * 10^{19}\ \mathrm{photons\ m^{-2}s^{-1}}\right) * (3{,}789 * 10^{-19}\ \mathrm{J\ photon^{-1}})$$

$$= 17{,}11 \pm 2{,}28\ \ \mathrm{Js^{-1}m^{-2}} =\ 17{,}11 \pm 2{,}28\ \mathrm{W\ m^{-2}} \rightarrow \mathrm{for\ 30\ minutes}$$

$$= (17{,}11 \pm 2{,}28\ \mathrm{W\ m^{-2}}) * (30 * 60) = 30793{,}20 \pm 4105{,}76\ \mathrm{J/m^{2}/day}$$

30793,20 ± 4105,76 J/m^2/day = 30,79 ± 4,11 KJ/m^2/day of green light from LEDs. The dose of green light that mites were exposed to in the 3 minutes of overlap with UV lamps was 3,1 ± 0,4 KJ/m^2/day.

Registration procedure

Registration of mites on the first and second true leaves was performed on the 14th and 21st day, respectively, after the initial infection. Each leaf was cut off with a scalpel and put with abaxial side up on a styrofoam block. Leaf circles with a diameter of 6 cm were cut using a leaf cutter, which was placed at the base of the leaf, close to the stem (figure 8 B). Extra attention was taken so that the central leaf nerve divided the leaf-circle in two equally sized halves. After each leaf-circle was cut, it was then transferred with pliers to its respective petri dish. After all samples were gathered, petri dishes were put in a styrofoam box for transfer to the laboratory. The samples were then put in a refrigerated room (Temperature: 2,1 ± 0,3°C) to stop reproduction and development while counting was performed. Counting of half the sampled leaves was conducted the same day as sampling, the rest of the samples were counted the following day. The last sample counted on the second day of registration was refrigerated for a maximum of 24 ± 6 hours. Counting was done under a Stereo loupe (Type: LEICA MZ16 magnifying used: 10X – 20X). When registering all first leaves, mites on the whole abaxial side of leaf-circles were counted. The second leaves were collected in the same way as the first leaves. Counting of second leaf-circles were done by counting only the left side of central nerve on the abaxial side, because of the considerable number of mites and the time it would take to count the full leaf.

The life-stages of mites registered during counting were divided into four groups: Eggs, larvae, nymphs and adults, alive and dead individuals were counted separately for each group. Larvae and protochryalis were counted as larvae, while Proto- and deutonymphs, deuto- and teleiochryalis were all counted as nymphs.

Counting mites on leaf circles was conducted in the following way; with the former apex of the leaf (figure 8 A) pointing away, starting at the bottom left corner off the leaf circle counting outwards and upwards. After the left side of the leaf was counted, the same process was done on the right side (first leaves), starting at the base of the leaf circle counting outwards and upwards (figure 8 A).

The purpose of the green light treatment was to lure the mites from the abaxial side of the leaf onto the axial side, thereby increasing UV exposure. Consequently, the registration method was updated to include both sides of leaves following the first registration of experiment 5. Registration of mites on both abaxial and axial sides of the leaf circles was conducted by placing the cut leaf-disc on top of an empty petri dish (5.8 cm diameter) with the axial side up, then carefully placing the petri-lid on top, squeezing the excess edges of the leaf between the petri-dish lid and bottom, keeping the leaf taut. This method worked well for counting both sides of leaf-circles, because mites were not harmed due to their small size and since leaf trichomes created a small gap between the lid and leaf. In the fifth experiment, registration of second leaves was done by counting half the axial and half of the abaxial side of the leaf. While in experiment six the whole leaf was counted on both sides during both registrations, this was to make sure that half count registrations were representative.

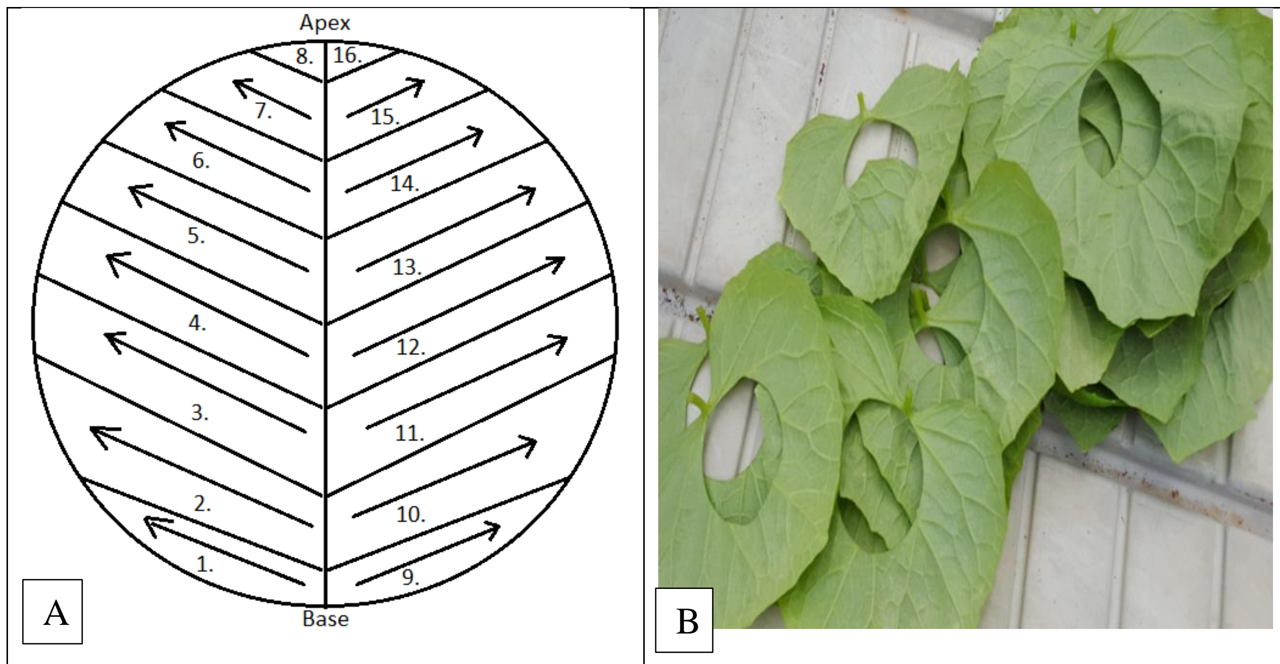


Figure 8. Counting method for leaf-circles (A). the entire leaf was counted during first registrations, only the left side was counted during second registrations in experiment 1-5. In experiment 6 the whole leaf was counted on both sides in both registrations. Example of where on the leaf, leaf-circles were cut (B).

For a summary of the treatment combinations conducted in each experiment and how treatments are referred to in the following results section see table 1.

Table 1.Overview of the treatment variables and treatment combinations tested in all experiments. Colored squares show variable combinations and how they are referred to in the text.

Treatments in experiment 1-3			Treatments in experiment 4-5			Treatments in experiment 6		
	+ UV	- UV		+ UV	- UV		+ UV + Reflector	- UV
+ Reflector	(UV + reflector)	(Reflector)	+ Green LED	(UV + green LED)	(Green LED)	+ Green LED	(UV + reflector + green LED)	(Green LED)
- Reflector	(UV)	(Control)	- Green LED	(UV)	(Control)	- Green LED	(UV + reflector)	(Control)

Statistics

The mortality data was calculated in Excel by dividing dead individuals against both dead and alive individuals, the proportions were then multiplied by 100 to get mortality percentage ((dead/(alive + dead))*100). Number of mites per cm^2 (mites/cm^2) was calculated by dividing numbers of mites against the amount of square cm in each registration (amount of mites/X cm^2), this was done for both total (alive+dead) and alive mites. The change in number of mites from first to second leaf (change/cm^2) was done by using mites/cm^2 numbers and subtracting the numbers from the first leaf, from the second leaf ((leaf 2 mites/cm^2) – (leaf 1 mites/cm^2)). Ratio between axial and abaxial (ratio) sides of leaves in experiment 5 and 6, were calculated by dividing mites on the axial side against the total amount of mites on both sides of each leaf ((mites on axial side)/(mites on axial and abaxial))

The treatments were compared using ordinary ANOVA models, optionally followed by Tukey's multiple comparison method. Comparisons were made both for total pooled (all life-stages) and within each life-stage. The response variables were mortality, mites/cm^2, change/cm^2, and ratios for all experiments. All comparisons conducted used 0.05 as the significance level. The calculations were performed using the General Linear Models (GLM) module in Minitab 16.

Results

Experiment 1

The first experiment showed significant difference in mortality when all life-stages of *T. urticae* were pooled in the second registration, within the treatment which combined UV exposure and a reflector (figure 9 B). The UV and reflector treatment affected the mortality of larvae and nymphs (Table 2). As stated, in the first experiment; new shoots were cut regularly and plants were given nutrient solution. This seems to have influenced the results, as the plants appeared to become stressed and affected by nutrient accumulation (figure 19). Consequently, in all experiments that followed, plants were only cut once (32 ± 5 days after seeding) and were only given water not containing nutrients (figure 20).

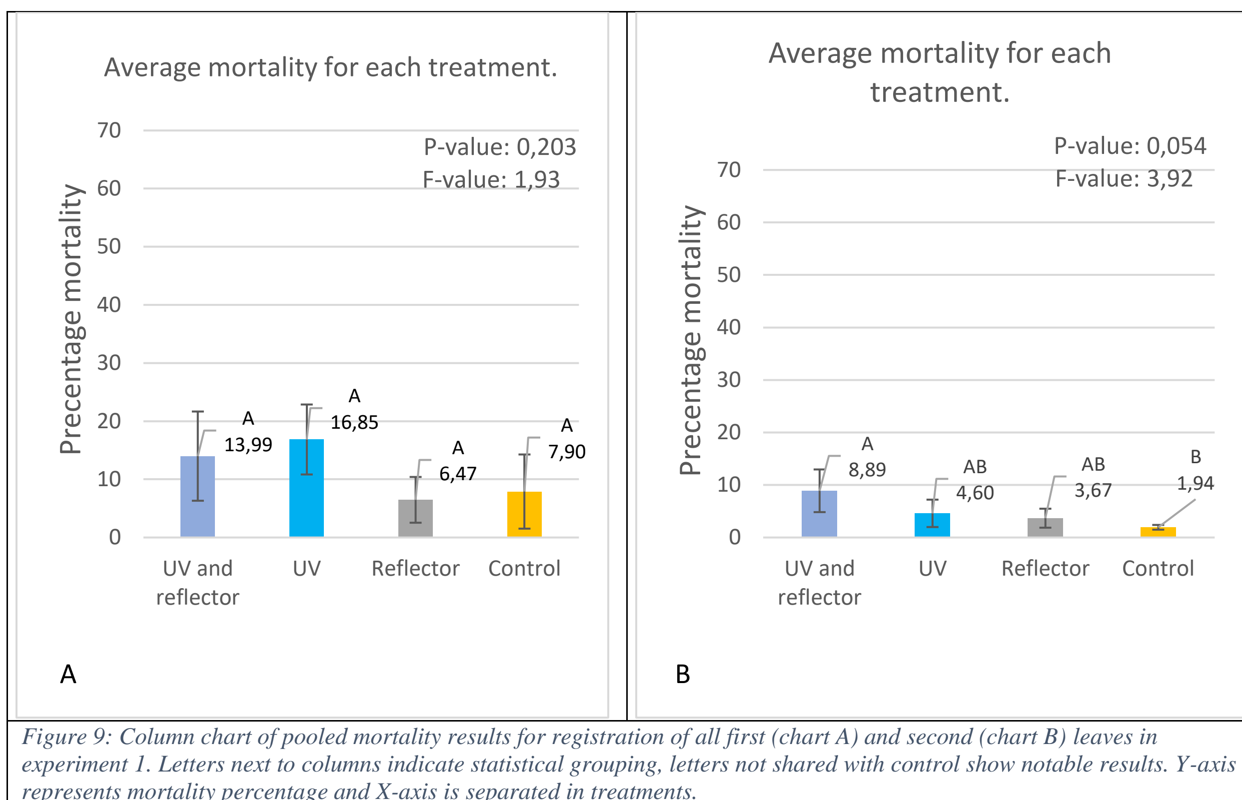


Figure 9: Column chart of pooled mortality results for registration of all first (chart A) and second (chart B) leaves in experiment 1. Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represents mortality percentage and X-axis is separated in treatments.

Table 2. Overview of mortality for each life-stage in experiment 1. Letters A and B denote the statistical grouping. Letters differing are statistically significant. Results which are noteworthy and differ from control are colored. Numbers represent the mean percentage of mortality.

Experiment conducted: 15.03.2017 - 05.04.2017

			Treatment					
Exp.no	**Leaf. no. (side of leaf):**	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
1	**1 (Abaxial)**	**Eggs**	A 15,5	A 14,1	A 7,9	A 11,1	0,70	0,580
	1 (Abaxial)	**Larvae**	A 17,1	A 25,2	A 11,9	A 9,6	1,60	0,265
	1 (Abaxial)	**Nymphs**	A 11,3	A 18,9	A 4,4	A 3,8	2,31	0,153
	1 (Abaxial)	**Adults**	A 2,2	A 9,2	A 2,8	A 5,0	1,17	0,381
	2 (Abaxial)	**Eggs**	A 8,3	A 5,9	A 1,9	A 1,6	2,39	0,145
	2 (Abaxial)	**Larvae**	A 9,8	AB 4,8	B 3,0	B 1,3	6,90	0,013
	2 (Abaxial)	**Nymphs**	A 17,4	AB 7,7	AB 3,0	B 0,8	4,64	0,037
	2 (Abaxial)	**Adults**	A 13,8	A 7,7	A 7,7	A 14,6	1,45	0,298

Experiment 2

In experiment 2, UV + reflector significantly affected the mortality in both registrations when life-stages were pooled (figure 10 A and B), eggs had sustained most of the mortality in both registrations, while the larval stage was also affected in registration of second leaves (Table 3)

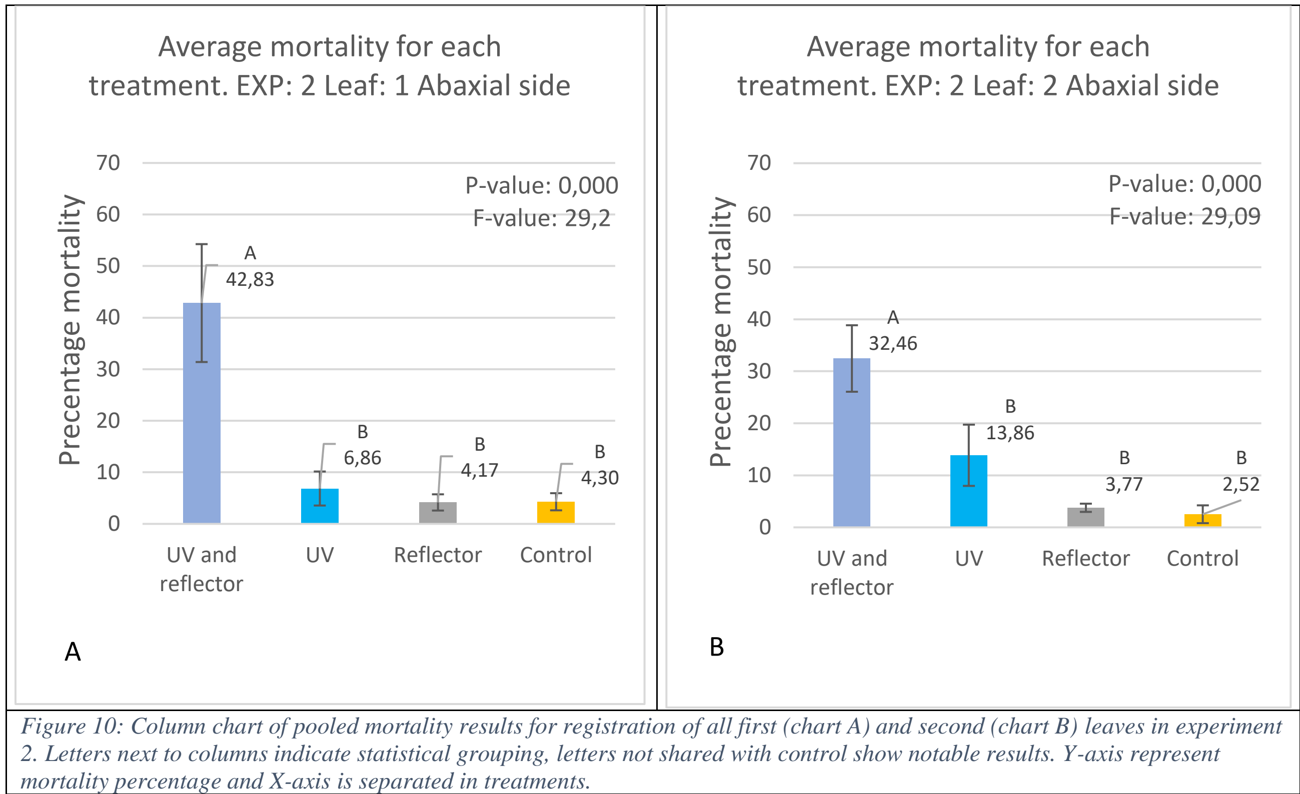


Figure 10: Column chart of pooled mortality results for registration of all first (chart A) and second (chart B) leaves in experiment 2. Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represent mortality percentage and X-axis is separated in treatments.

Table 3. Overview of mortality for each life-stage in experiment 2. Letters A and B denote the statistical grouping. Letters differing are statistically significant. Results which are noteworthy and differ from control are colored. Numbers represent the mean percentage of mortality.

Experiment conducted: 20.04.2017- 11.05.2017			**Treatment**					
Exp.no	**Leaf. no. (side of leaf):**	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
2	**1 (Abaxial)**	**Eggs**	A 53,6	B 7,6	B 5,6	B 2,8	25,66	0,000
	1 (Abaxial)	**Larvae**	A 14,4	A 11,2	A 5,9	A 1,3	0,98	0,451
	1 (Abaxial)	**Nymphs**	A 2,1	A 4,0	A 7,4	A 8,9	1,71	0,242
	1 (Abaxial)	**Adults**	A 0,0	A 4,5	A 3,5	A 5,1	0,95	0,46
	2 (Abaxial)	**Eggs**	A 38,6	B 18,9	B 5,3	B 3,8	22,94	0,000
	2 (Abaxial)	**Larvae**	A 12,6	AB 7,7	B 2,4	B 1,5	12,54	0,002
	2 (Abaxial)	**Nymphs**	A 7,0	A 5,7	A 2,3	A 1,5	1,64	0,255
	2 (Abaxial)	**Adults**	A 16,7	A 15,9	A 7,4	A 8,5	2,09	0,179

Experiment 3

The treatment that combined UV and reflectors in experiment 3 also had significant effect on the mortality of eggs after two weeks (first registration) and affected all life-stages in the registration of second leaves (Table 4). The mortality which occurred in the adult stage during the second registration is most likely caused by the small number of adult mites in general (appendix 2), and is therefore not considered significant.

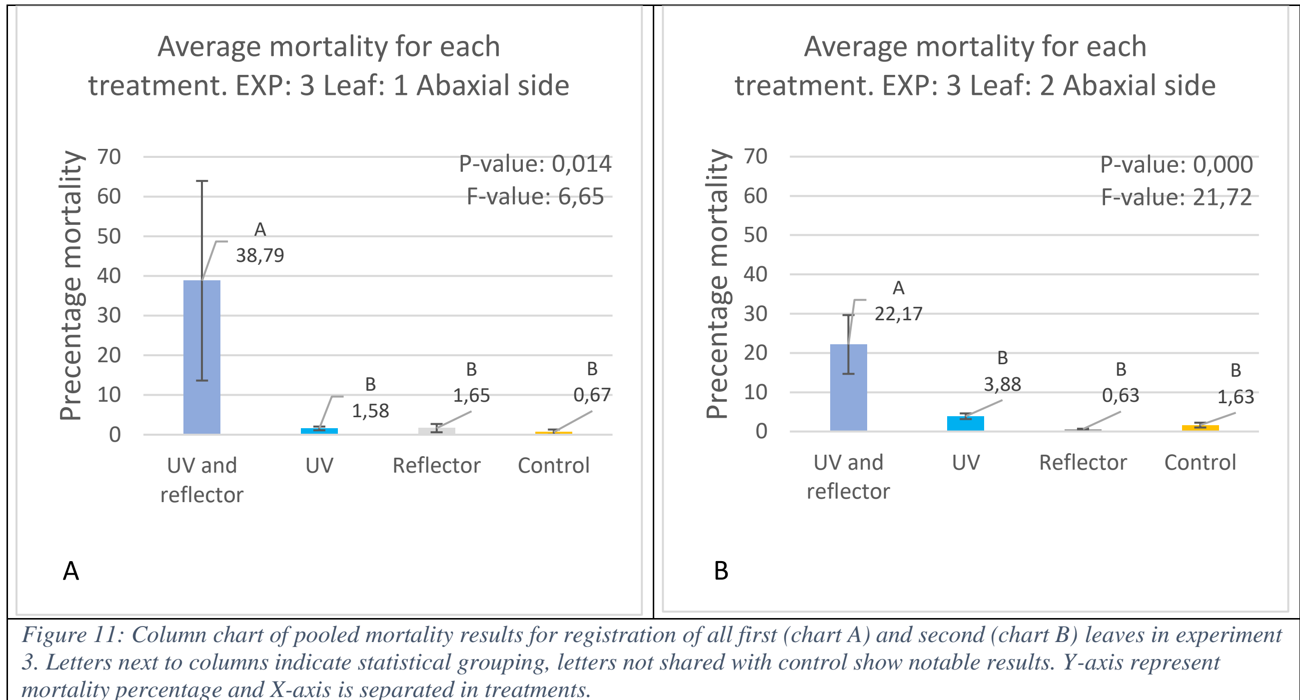


Figure 11: Column chart of pooled mortality results for registration of all first (chart A) and second (chart B) leaves in experiment 3. Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represent mortality percentage and X-axis is separated in treatments.

Table 4. Overview of mortality for each life-stage in experiment 3. Letters A and B denote the statistical grouping. Letters differing are statistically significant. Results which are noteworthy and differ from control are colored. Numbers represent the mean percentage of mortality.

Experiment conducted: 21.06.217 – 17.07.2017

			Treatment					
Exp.no	**Leaf. No. (side of leaf):**	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
3	**1 (Abaxial)**	**Eggs**	A 46,6	B 1,5	B 1,5	B 0,7	7,91	0,009
	1 (Abaxial)	**Larvae**	A 30,2	A 1,8	A 8,9	A 1,0	2,79	0,110
	1 (Abaxial)	**Nymphs**	A 0,0	A 1,6	A 0,0	A 0,7	4,01	0,052
	1 (Abaxial)	**Adults**	A 3,0	A 1,4	A 0,0	A 0,0	0,74	0,557
	2 (Abaxial)	**Eggs**	A 23,0	B 4,1	B 0,4	B 1,8	16,36	0,001
	2 (Abaxial)	**Larvae**	A 13,5	B 2,7	B 0,6	B 0,6	16,28	0,001
	2 (Abaxial)	**Nymphs**	A 31,1	B 4,8	B 1,3	B 5,9	7,80	0,009
	2 (Abaxial)	**Adults**	A 43,1	AB13,6	B 4,6	B 3,0	7,71	0,010

Experiment 4

Experiment 4 was the first experiment conducted with green LEDs, the LEDs light had no discernable effect on mortality, on the abaxial side. Although the UV treatment affected the mortality of larval-stage *T. urticae* in both registrations and eggs in the second registration (table 5), The mortality rates were quite low and become less noteworthy when compared with mortality occurring in the same treatment, in experiment 1-3. The statistical significance arises from the low mortality in compared treatments, but are within the range of mortality results occurring in the UV treatment in general.

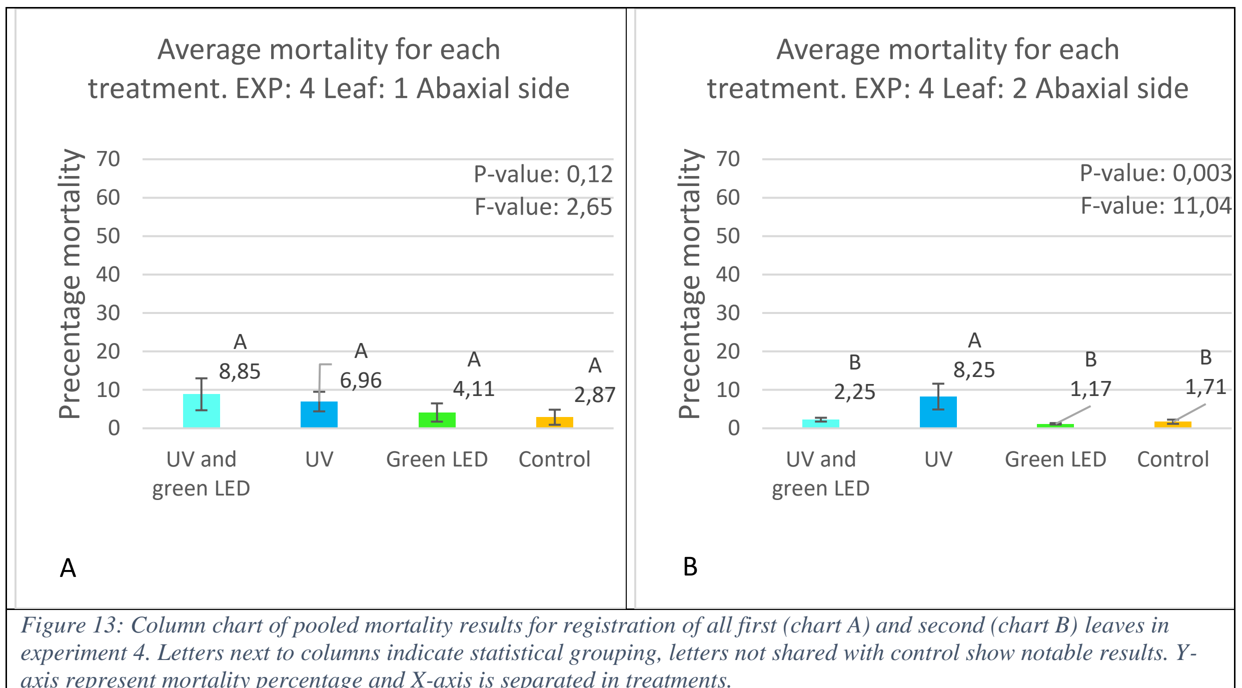


Figure 13: Column chart of pooled mortality results for registration of all first (chart A) and second (chart B) leaves in experiment 4. Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represent mortality percentage and X-axis is separated in treatments.

Table 5. Overview of mortality for each life-stage in experiment 4. Letters A and B denote the statistical grouping. Letters differing are statistically significant. Results which are noteworthy and differ from control are colored. Numbers represent the mean percentage of mortality.

Experiment conducted: 03.08.2017 – 24.08.2017			**Treatment**					
Exp.no	**Leaf. No. (side of leaf):**	**Life-stage:**	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
4	**1 (Abaxial)**	**Eggs**	A 11,8	A 7,6	A 4,8	A 4,6	1,15	0,386
	1 (Abaxial)	**Larvae**	B 1,9	A 18,9	B 2,8	B 0,0	20,69	0,000
	1 (Abaxial)	**Nymphs**	A 3,7	A 2,3	A 0,9	A 0,7	4,16	0,047
	1 (Abaxial)	**Adults**	A 9,3	A 8,4	A 6,1	A 2,0	1,54	0,279
	2 (Abaxial)	**Eggs**	B 2,3	A 12,0	B 0,6	B 1,4	7,11	0,012
	2 (Abaxial)	**Larvae**	B 1,8	A 6,2	B 0,7	B 0,9	14,43	0,001
	2 (Abaxial)	**Nymphs**	A 2,2	A 2,8	A 1,4	A 3,2	0,58	0,642
	2 (Abaxial)	**Adults**	A 17,3	A 10,0	A 23,3	A 16,5	1,84	0,218

Experiment 5

None of the UV or green light treatments had a significant effect on mortality on the abaxial side of leaves in both registrations in experiment 5 (figure 14 and 15 B). Before registration of all second leaves, the registration method was updated to include both sides of all leaves. Registration of the axial side of second leaves showed that significant mortality had occurred in nymph-stages of *T. urticae* within the treatments containing UV + green LED light and UV (figure 15 A and Table 6).

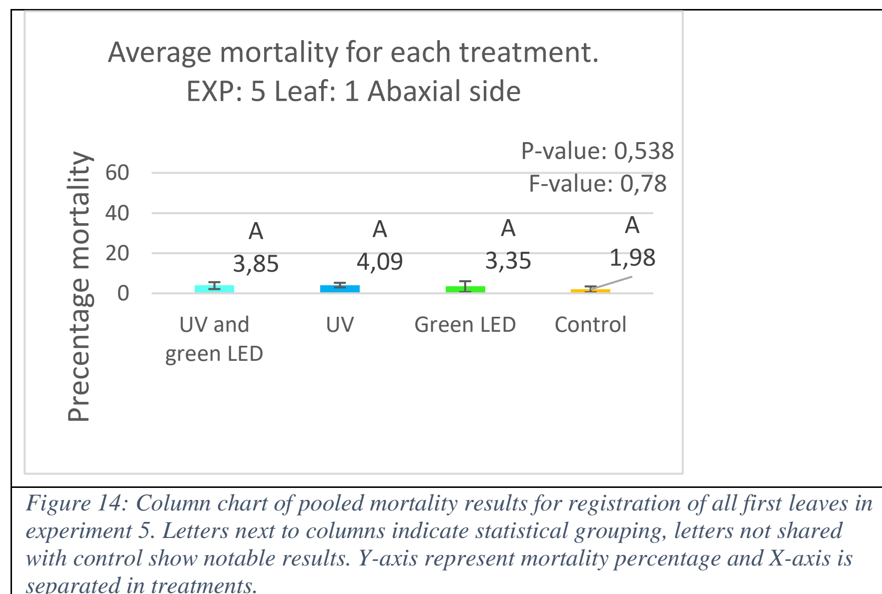


Figure 14: Column chart of pooled mortality results for registration of all first leaves in experiment 5. Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represent mortality percentage and X-axis is separated in treatments.

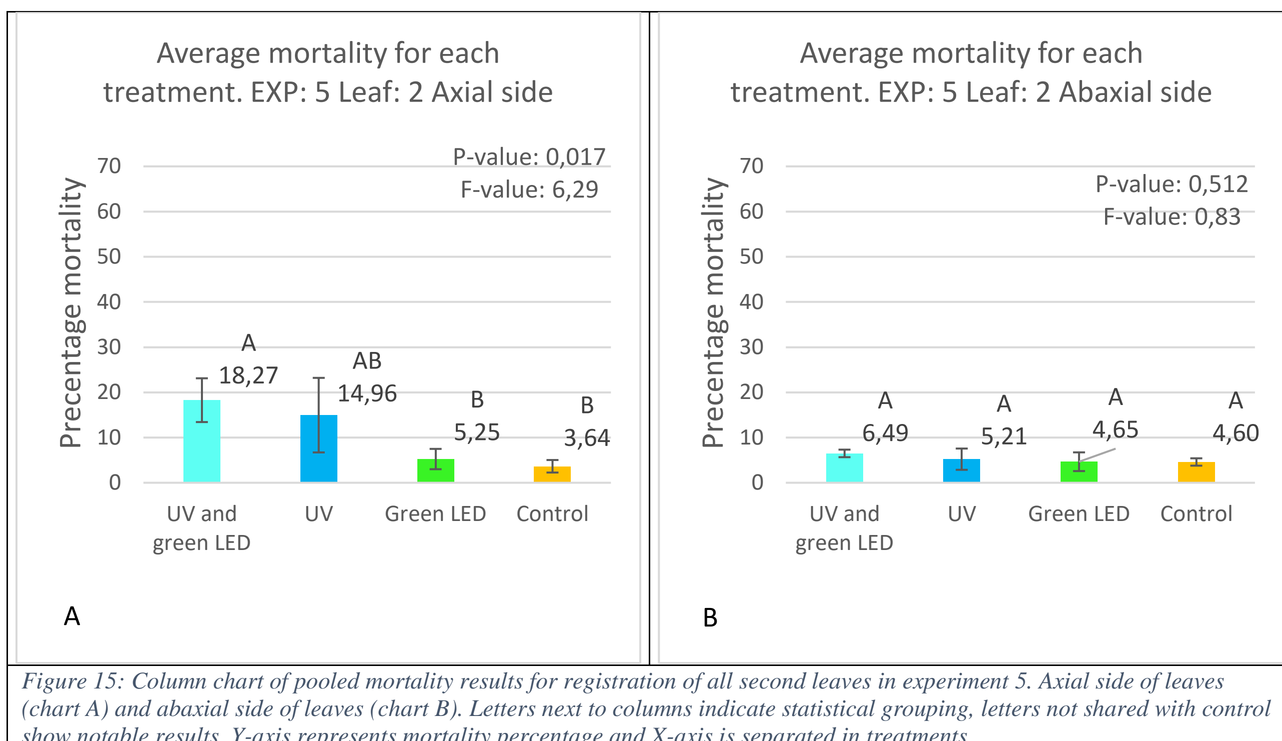


Figure 15: Column chart of pooled mortality results for registration of all second leaves in experiment 5. Axial side of leaves (chart A) and abaxial side of leaves (chart B). Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represents mortality percentage and X-axis is separated in treatments.

Table 6. Overview of mortality for each life-stage in experiment 5. Letters A and B denote the statistical grouping. Letters differing are statistically significant. Results which are noteworthy and differ from control are colored. Numbers represent the mean percentage of mortality.

Experiment conducted:
31.08.2017 – 21.09.2017

			Treatment					
Exp.no	**Leaf. No. (side of leaf):**	**Life-stage:**	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
5	**1 (Abaxial)**	**Eggs**	A 6,3	A 5,1	A 6,3	A 5,2	0,10	0,960
	1 (Abaxial)	**Larvae**	A 3,2	A 8,0	A 6,0	A 0,0	2,80	0,109
	1 (Abaxial)	**Nymphs**	A 2,6	A 1,9	A 1,5	A 1,4	0,51	0,686
	1 (Abaxial)	**Adults**	A 0,9	A 4,0	A 2,9	A 0,0	3,13	0,088
	2 (Abaxial)	**Eggs**	A 6,4	A 6,1	A 7,2	A 5,8	0,16	0,917
	2 (Abaxial)	**Larvae**	A 4,2	A 4,1	A 1,6	A 1,7	1,85	0,217
	2 (Abaxial)	**Nymphs**	A 11,1	A 4,2	A 4,3	A 3,6	1,06	0,417
	2 (Abaxial)	**Adults**	A 15,1	A 7,1	A 3,6	A 11,6	1,60	0,265
	2 (Axial)	**Eggs**	A 16,1	A 16,4	A 12,2	A 5,7	2,04	0,187
	2 (Axial)	**Larvae**	A 19,3	AB 14,6	B 1,7	AB 3,4	5,51	0,024
	2 (Axial)	**Nymphs**	A 18,2	A 26,9	B 1,3	B 2,9	14,87	0,001
	2 (Axial)	**Adults**	A 17,4	A 7,1	A 7,6	A 2,4	1,36	0,323

Experiment 6

In experiment 6, mites on both axial and abaxial sides of the leaf were counted during both registrations. The treatment with UV+ Green LED + Reflector, showed consistent significant effect on overall mortality across both registrations (figure 16 – 17), affecting all but the adult stage of *T. urticae* (Table 7). The UV and reflector treatment inflicted notable mortality compared to control when life-stages were pooled on the abaxial side of the first registration, as well as both sides of the leaves in the second registration (figure 16 B and figure 17). The treatment affected mostly larvae, followed by nymph- and egg stages (Table 7).

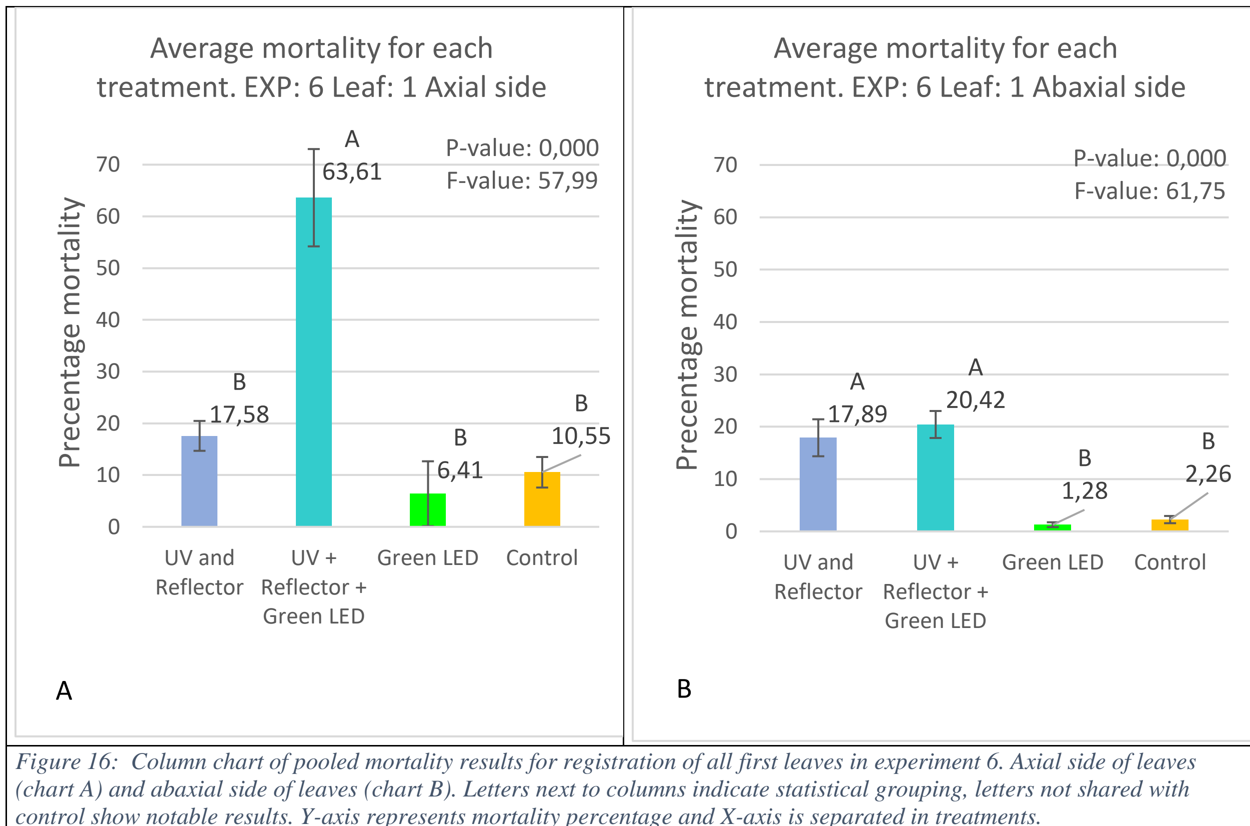


Figure 16: Column chart of pooled mortality results for registration of all first leaves in experiment 6. Axial side of leaves (chart A) and abaxial side of leaves (chart B). Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represents mortality percentage and X-axis is separated in treatments.

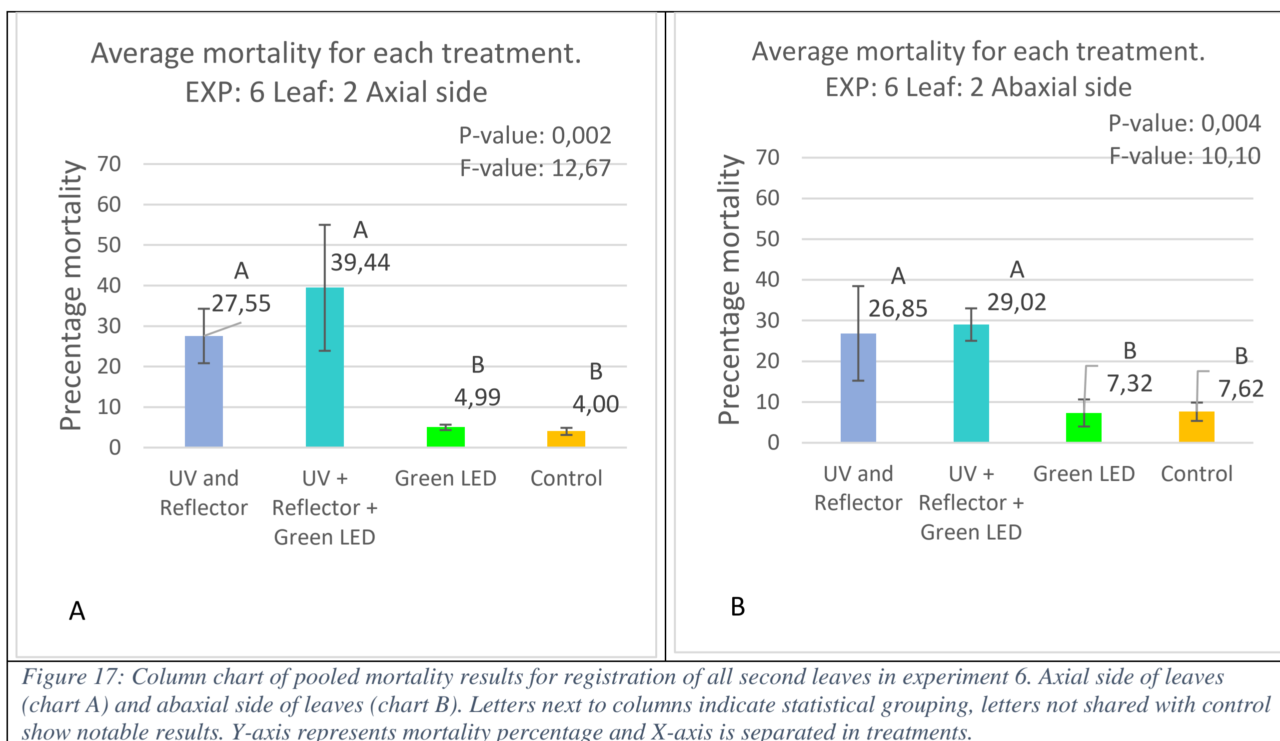


Figure 17: Column chart of pooled mortality results for registration of all second leaves in experiment 6. Axial side of leaves (chart A) and abaxial side of leaves (chart B). Letters next to columns indicate statistical grouping, letters not shared with control show notable results. Y-axis represents mortality percentage and X-axis is separated in treatments.

Table 7. Overview of mortality for each life-stage in experiment 6. Letters A, B and C denote the statistical grouping. Letters differing are statistically significant. Results which are noteworthy and differ from control are colored. Numbers represent the mean percentage of mortality.

Experiment conducted: 14.10.2017 – 04.11.2017

			Treatment					
Exp.no	**Leaf. No. (side of leaf):**	**Life-stage:**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6	**1 (Abaxial)**	**Eggs**	B 22,7	A 31,7	C 1,5	C 2,5	74,80	0,000
	1 (Abaxial)	**Larvae**	A 25,1	A 22,7	B 0,0	AB 9,8	7,45	0,011
	1 (Abaxial)	**Nymphs**	A 7,4	A 7,4	AB 1,5	B 0,9	7,13	0,012
	1 (Abaxial)	**Adults**	A 8,5	A 4,0	A 1,5	A 0,0	3,42	0,073
	1 (Axial)	**Eggs**	B 29,5	A 76,8	B 9,1	B 24,8	17,79	0,001
	1 (Axial)	**Larvae**	B 25,5	A 51,1	BC 8,2	C 4,8	25,56	0,000
	1 (Axial)	**Nymphs**	A 9,9	A 10,4	A 1,3	A 0,4	3,02	0,094
	1 (Axial)	**Adults**	A 2,6	A 13,9	A 1,0	A 1,6	1,42	0,306
	2 (Abaxial)	**Eggs**	A 34	A 37,5	A 14,4	A 16,7	4,87	0,033
	2 (Abaxial)	**Larvae**	A 13,6	A 11,6	B 2,4	B 3,0	15,25	0,001
	2 (Abaxial)	**Nymphs**	A 9,1	A 10,5	B 3,0	B 2,3	36,51	0,000
	2 (Abaxial)	**Adults**	A 10,1	A 19,3	A 0,0	A 11,9	1,51	0,285
	2 (Axial)	**Eggs**	AB 28,8	A 46	B 11,3	B 8,9	7,03	0,012
	2 (Axial)	**Larvae**	A 26,7	A 35,1	B 1,6	B 0,7	12,71	0,002
	2 (Axial)	**Nymphs**	AB 21,4	A 36,7	B 1,0	B 1,4	8,65	0,007
	2 (Axial)	**Adults**	A 10,6	A 20,1	A 4,3	A 11,3	2,45	0,138

Comperative results

Compared to the UV-, reflector-, UV + green LED and control treatments, UV combined with reflectors had a consistent effect on the mortality of *T. urticae* when life-stages were pooled in all experiments (Table 8). The relatively low mortality found in experiment 4 and 5 occurred mostly within the UV treatment (table 9), but there was some indication that the combination of green light and UV could increase mortality on the axial side of leaves (table 8). The treatment that combined green LED, UV and reflector in experiment 6, was somewhat more effective than the combination of UV and reflector (Table 8 and 9). When significantly higher mortality resulted from the different UV treatments, it always occurred in egg-, larvae-, ecdysis or nymph stages in all experiments (table 9). The only result that deviated from this pattern was the effect that UV combined with reflector had on adult *T. urticae* in the second registration of experiment 3 (table 9), the significance could be owed to the small amount of adults/cm^2 observed in general (Appendix 2). As was expected, the treatments which used only either reflector or Green LED lights, did not have any effect on mortality in any of the experiments (table 8 – 9).

Table 8. Pooled mortality results for each registration of all experiments. Letters A and B denote the statistical grouping. Letters not shared with control are significant. Numbers represent the mean percentage of mortality.

		Treatment					
Exp.no	**Leaf. No. (leaf side)**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value:**	**P-value:**
1	1 (Abaxial)	A 14,0	A 16,9	A 6,5	A 7,9	1,93	0,203
	2 (Abaxial)	A 8,9	AB 4,6	AB 3,7	B 1,9	3,92	0,054
2	1 (Abaxial)	A 42,8	B 6,9	B 4,2	B 4,3	29,20	0,000
	2 (Abaxial)	A 32,5	B 13,9	B 3,8	B 2,5	29,09	0,000
3	1 (Abaxial)	A 38,8	B 1,6	B 1,7	B 20,7	6,65	0,014
	2 (Abaxial)	A 22,2	B 3,9	B 0,6	B 1,6	21,72	0,000
Exp.no	**Leaf. No. (leaf side)**	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value:**	**P-value:**
4	1 (Abaxial)	A 8,8	A 7,0	A 4,1	A 2,9	2,65	0,120
	2 (Abaxial)	B 2,3	A 8,2	B 1,2	B 1,7	11,04	0,003
5	1 (Abaxial)	A 3,9	A 4,1	A 3,3	A 2,0	0,78	0,538
	2 (Abaxial)	A 6,5	A 5,2	A 4,7	A 4,6	0,83	0,512
	2 (Axial)	A 18,3	AB 15,0	B 5,2	B 3,6	6,29	0,017
Exp.no	**Leaf. No. (leaf side)**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value:**	**P-value:**
6	1 (Abaxial)	A 17,9	A 20,4	B 1,3	B 2,3	61,75	0,000
	1 (Axial)	B 17,6	A 63,6	B 6,4	B 10,6	57,99	0,000
	2 (Abaxial)	A 26,9	A 29,0	B 7,3	B 7,6	10,10	0,004
	2 (Axial)	A 27,6	A 39,4	B 5,0	B 4,0	12,67	0,002

Table 9. Summary of the mortality results that occurred in each life-stage which were significantly higher than control. Letters A, B and C denote the statistical grouping. Letters not shared with control are significantly different. Numbers represent the mean percentage of mortality.

		Treatment					
EXP no. Leaf no. (leaf side)	***Life-stage:***	**UV + Reflector**	**UV**	**Reflector**	**Control**	***F-value***	***P-value***
1.2 (Abaxial)	**Larvae**	A 9,8	AB 4,8	B 3,0	B 1,3	6,90	0,013
1.2 (Abaxial)	**Nymphs**	A 17,4	AB 7,7	AB 3	B 0,8	4,64	0,037
2.1 (Abaxial)	**Eggs**	A 53,6	B 7,6	B 5,6	B 2,8	25,66	0,000
2.2 (Abaxial)	**Eggs**	A 38,6	B 18,9	B 5,3	B 3,8	22,94	0,000
2.2 (Abaxial)	**Larvae**	A 12,6	AB 7,7	B 2,4	B 1,5	12,54	0,002
3.1 (Abaxial)	**Eggs**	A 46,6	B 1,5	B 1,5	B 0,7	7,91	0,009
3.2 (Abaxial)	**Eggs**	A 23,0	B 4,1	B 0,4	B 1,8	16,36	0,001
3.2 (Abaxial)	**Larvae**	A 13,5	B 2,7	B 0,6	B 0,6	16,28	0,001
3.2 (Abaxial)	**Nymphs**	A 31,1	B 4,8	B 1,3	B 5,9	7,80	0,009
3.2 (Abaxial)	**Adults**	A 43,1	AB 13,6	B 4,6	B 3,0	7,71	0,010
EXP no. Leaf no. (leaf side)	***Life-stage:***	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
4.1 (Abaxial)	**Larvae**	B 1,9	A 18,9	B 2,8	B 0,0	20,69	0,000
4.2 (Abaxial)	**Eggs**	B 2,3	A 12,0	B 0,6	B 1,4	7,11	0,012
4.2 (Abaxial)	**Larvae**	B 1,8	A 6,2	B 0,7	B 0,9	14,43	0,001
5.2 (Axial)	**Nymphs**	A 18,2	A 26,9	B 1,3	B 2,9	14,87	0,001
EXP no. Leaf no. (leaf side)	***Life-stage:***	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6.1 (Abaxial)	**Eggs**	B 22,7	A 31,7	C 1,5	C 2,5	74,8	0,000
6.1 (Abaxial)	**Nymphs**	A 7,4	A 7,4	AB 1,5	B 0,9	7,13	0,012
6.1 (Axial)	**Eggs**	B 29,5	A 76,8	B 9,1	B 24,8	17,79	0,001
6.1 (Axial)	**Larvae**	B 25,5	A 51,1	BC 8,2	C 4,8	25,56	0,000
6.2 (Abaxial)	**Larvae**	A 13,6	A 11,6	B 2,4	B 3,0	15,25	0,001
6.2 (Abaxial)	**Nymphs**	A 9,1	A 10,5	B 3,0	B 2,3	36,51	0,000
6.2 (Axial)	**Eggs**	AB 28,8	A 46	B 11,3	B 8,9	7,03	0,012
6.2 (Axial)	**Larvae**	A 26,7	A 35,1	B 1,6	B 0,7	12,71	0,002
6.2 (Axial)	**Nymphs**	AB 21,4	A 36,7	B 1,0	B 1,4	8,65	0,007

The number of alive mites per square cm was compared between treatments, to see if there were significant differences between treatments that could not be explained by the mortality results. In experiment 1 and 2, there was a significantly higher number of alive individuals both within the UV and the reflector treatment (table 10). The rest of the notable results were significantly lower than control and correlate with mortality results in tables 8, 9 and 10.

Table 10. summary of statistically significant results obtained from comparison of alive mites/cm2 for each life-stage and pooled life-stages (LS). Letters denote statistical grouping and number are mean amount of alive mites/m2.

		Treatments					
EXP no. Leaf no. (leaf side)	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
1.1 (Abaxial)	**Larvae**	AB 1,2	A 2	B 0,9	B 1,1	6,62	0,015
1.2 (Abaxial)	**Nymphs**	C 1,3	AB 4,5	A 5,6	BC 2,8	10,48	0,004
2.1 (Abaxial)	**Larvae**	B 0,4	A 1,6	B 0,5	B 0,7	29,87	0,000
2.1 (Abaxial)	**Nymphs**	B 0,7	A 2,2	B 0,8	B 1,0	7,76	0,009
2.1 (Abaxial)	**Adults**	C 0,3	A 1,4	BC 0,7	B 0,9	16,47	0,001
2.2 (abaxial) Pooled LS:		B 26,9	AB 50,1	A 57,7	A 55,4	6,50	0,015
3.2 (abaxial) Pooled LS:		B 29,7	AB 56,6	A 68,7	A 70,7	5,86	0,02
EXP no. Leaf no. (leaf side)	**Life-stage:**	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
4.2 (Abaxial)	**Eggs**	AB 19,5	B 13,9	A 25,0	A 25,3	5,99	0,019
4.2 (abaxial) Pooled LS:		AB 38,4	B 31,8	A 48,7	A 44,7	10,30	0,004
EXP no. Leaf no. (leaf side)	**Life-stage:**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6.1 (Axial)	**Nymphs**	AB 1,5	B 1,2	AB 2,4	A 2,6	7,01	0,013
6.1 (Abaxial)	**Eggs**	AB 3,4	B 2,0	A 4,5	A 4,4	5,56	0,023
6.1 (abaxial) Pooled LS:		AB 6,7	B 4,7	A 9,3	A 9,0	6,20	0,018
6.2 (Axial)	**Larvae**	B 7,3	B 8,2	A 18,5	A 18,6	23,30	0,000
6.2 (Axial)	**Nymphs**	B 3,1	B 2,2	A 15,2	A 14,7	41,79	0,000
6.2 (axial) Pooled LS:		BC 30,2	C 20,3	A 54,5	AB 52,8	11,38	0,003
6.2 (Abaxial)	**Nymphs**	AB 3,0	B 2,3	AB 6,4	A 8,2	5,25	0,027

To see whether there were differences in population size, which may have been caused by something else than mortality from UV and was not detected in amount of alive mites/cm^2, the total (alive + dead) amount of mites per cm^2 was calculated and compared between treatments. When life-stages were pooled, the results from the analysis showed that there were significantly more mites in both UV and the UV + reflector treatments in experiment 1. In experiment 4, there were significantly less mites in the UV treatment (table 11). However, the significance was evenly spread out across life-stages, and did not appear in any specific life-stage when tested separately (table 12).

Table 11. Mean number of total (all life-stages both dead and alive) mites per square cm for both registrations in all experiments. Letters A, and B denote the statistical grouping. Letters not shared with control are significant. Numbers are the mean amount of mites per square cm.

		Treatment					
Exp.no	***Leaf. No.***	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
1	**1 (Abaxial)**	A 9,7	A 10,0	AB 9,3	B 6,2	5,48	0,024
	2 (Abaxial)	A 47,9	A 72,9	A 59,3	A 52,1	0,79	0,532
2	**1 (Abaxial)**	AB 6,0	A 12,2	B 4,3	AB 6,1	5,14	0,028
	2 (Abaxial)	A 40,5	A 58,2	A 60,0	A 57,3	2,10	0,179
3	**1 (Abaxial)**	A 6,6	A 9,2	A 3,8	A 6,6	2,50	0,134
	2 (Abaxial)	A 37,8	A 58,8	A 69,1	A 71,9	3,83	0,057
Exp.no	***Leaf. No.***	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
4	**1 (Abaxial)**	A 6,8	A 10,2	A 5,4	A 7,2	2,51	0,132
	2 (Abaxial)	AB 39,3	B 34,6	A 49,3	A 45,4	7,52	0,010
5	**1 (Abaxial)**	A 11,2	A 12,0	A 8,6	A 8,8	1,37	0,321
	2 (Axial)	A 29,4	A 25,0	A 42,4	A 49,6	2,41	0,142
	2 (Abaxial)	A 27,8	A 38,7	A 41,7	A 37,8	1,03	0,430
Exp.no	***Leaf. No.***	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6	**1 (Axial)**	B 5,0	A 11,3	AB 7,4	AB 8,4	4,39	0,042
	1 (Abaxial)	A 8,2	A 5,9	A 9,4	A 9,2	2,54	0,130
	2 (Axial)	A 42,6	A 31,9	A 57,3	A 55,0	3,81	0,058
	2 (Abaxial)	A 30,5	A 25,7	A 32,1	A 31,1	0,24	0,866

When the amount of alive and dead mites per cm^2 were compared for each life-stage (table 12), there were significantly more mites observed in the UV treatment for experiment one and two. In experiment 6 There were significantly less larvae and nymphs per cm^2 in the treatments combining both UV + reflector and UV + reflector + green LEDs compared to control. The treatment which combined UV ad reflectors had significantly less adult mites in the first registration of experiment two, while the UV treatment showed the opposite and had significantly more adults. There were also significantly more eggs in the first registration of experiment six within the UV + reflector + green LED treatment.

Table 12. amount of total (alive and dead) mites/cm^2. Only results with a statistical significance are listed. A, B and C denote statistical grouping, numbers represent mean amount of mites

		Treatment					
Experiment #. Leaf # (leaf side):	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
1.1 (Abaxial)	**Larvae**	B 1,4	A 2,6	B 1,0	B 1,2	15,28	0,001
1.2 (Abaxial)	**Larvae**	B 7,2	A 17,7	AB 13,8	B 10,2	9,42	0,005
2.1 (Abaxial)	**Larvae**	B 0,5	A 2,3	B 0,5	B 0,7	22,64	0,000
2.1 (Abaxial)	**Nymphs**	B 0,7	A 2,3	B 0,8	B 1,0	8,44	0,007
2.1 (Abaxial)	**Adults**	C 0,3	A 1,5	BC 0,7	B 0,9	17,92	0,001
Experiment #. Leaf # (leaf side):	**Life-stage:**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value:**	**P-value:**
6.1 (Axial)	**Eggs**	B 1,4	A 8,5	B 2,7	B 3,3	12,51	0,002
6.1 (Axial)	**Nymphs**	AB 1,7	B 1,4	AB 2,4	A 2,6	5,26	0,027
6.2 (Axial)	**Larvae**	B 9,8	B 12,3	A 18,8	A 18,7	15,85	0,001
6.2 (Axial)	**Nymphs**	B 3,8	B 3,5	A 15,3	A 14,9	34,26	0,000
6.2 (Abaxial)	**Nymphs**	AB 3,3	B 2,6	AB 6,6	A 8,4	4,68	0,036

To see whether there were differences between the treatments which were not picked up by neither mortality nor the number of mites per cm^2. Analysis of the amount change in mites/cm^2 from the first to second leaves was conducted (table 13 and 14). When life-stages were pooled (table 13) the only notable result that occurred was found in experiment 4, the treatment containing UV without reflectors showing significantly less reduction in the number of mites when compared to the other treatments. This result correlates with the only significant result from total amount of mites/cm^2 observed in second registration of experiment 4 (table 11), but as the significance is spread out evenly across life-stages rendering the change insignificant when life-stages were tested separately (table 14).

Table 103. The mean amount of change in mites/cm^2 between leaf 1 and 2 in each experiment (life-stages pooled). Letters A and B denote the statistical grouping. Letters not shared with control are significant. Numbers are the mean amount of change (mean amount mites/cm^2 leaf 2 – mean amount mites/cm^2 leaf 1). Colors mark results that where statistically significant.

	Treatment.					
Experiment. No.	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value:**	**P-value:**
1 (Abaxial)	B 34,1	AB 52,4	A 78,3	AB 50,9	4,42	0,041
2 (Abaxial)	A 34,5	A 46,1	A 55,6	A 51,2	2,13	0,175
3 (Abaxial)	A 31,2	A 49,6	A 65,3	A 65,3	3,98	0,052
Experiment. No.	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value:**	**P-value:**
4 (Abaxial)	AB 32,5	B 24,4	A 43,9	A 38,3	9,72	0,005
5 (Abaxial)	A 16,6	A 26,7	A 33,2	A 29,1	1,50	0,286
Experiment. No.	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value:**	**P-value:**
6 (Axial)	AB 37,7	B 20,6	A 49,9	AB 46,7	5,17	0,028
6 (Abaxial)	A 22,3	A 19,7	A 22,6	A 21,9	0,06	0,981

When separated into life-stages the amount of change from the first to the second leaf provided only significant lower values in experiment 2 and 6 (table 13). For experiment 2 there were less adults in the second registration than in the first, which gave a negative value. In experiment 6, the UV + reflector and UV + reflector + green LED treatments had a lower amount of change in larvae and nymph numbers. This could be caused by the high amount of mortality occurring in

these treatments (table 9). Which would reduce the amount of reproducing adults, resulting in a small number of both larvae and nymphs.

Table 114. The mean amount of change in mites/cm² between leaf 1 and 2 in each experiment, for each life-stage. Letters A, B and C denote the statistical grouping. Letters not shared with control are significant. Numbers represent the mean amount of change (mean amount mites/cm² leaf 2 – mean amount mites/cm² leaf 1), colors mark results that were statistically significant.

			Treatment					
Exp.no	**Leaf #:**	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**	**F-value**	**P-value**
1	**(abaxial)**	**Eggs**	A 27,1	A 34,2	A 61,2	A 40,2	3,41	0,074
	(abaxial)	**Larvae**	B 5,8	A 15,1	AB 12,7	AB 9,0	6,83	0,013
	(abaxial)	**Nymphs**	B 0,3	AB 2,5	A 4,2	AB 1,1	5,24	0,027
	(abaxial)	**Adults**	A 1,0	A 0,6	A 0,2	A 0,6	0,67	0,593
2	**(abaxial)**	**Eggs**	A 26,7	A 27,3	A 28,4	A 31,3	0,11	0,950
	(abaxial)	**Larvae**	B 4,2	AB 13,4	A 19,7	AB 14,3	6,39	0,016
	(abaxial)	**Nymphs**	A 2,3	A 5,7	A 7,2	A 4,7	1,70	0,243
	(abaxial)	**Adults**	A 1,2	C -0,3	BC 0,4	AB 0,8	14,97	0,001
3	**(abaxial)**	**Eggs**	A 26,3	A 35,3	A 38,4	A 48,9	2,38	0,145
	(abaxial)	**Larvae**	B 4,1	AB 14,6	A 21,1	AB 14,4	6,89	0,013
	(abaxial)	**Nymphs**	B 0,3	B -0,3	A 4,7	AB 2,1	6,29	0,017
	(abaxial)	**Adults**	A 0,4	A 0,0	A 1,1	A -0,1	2,09	0,179
Exp.no	**Leaf #:**	**Life-stage:**	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
4	**(abaxial)**	**Eggs**	A 16,3	A 9,8	A 21,9	A 21,4	3,99	0,052
	(abaxial)	**Larvae**	AB 13,0	B 9,3	A 15,4	AB 13,2	4,18	0,047
	(abaxial)	**Nymphs**	A 3,5	A 5,3	A 6,2	A 3,5	2,11	0,177
	(abaxial)	**Adults**	A -0,3	A -0,0	A 0,3	A 0,1	2,49	0,134
5	**(abaxial)**	**Eggs**	A 9,9	A 18,2	A 18,2	A 20,7	1,06	0,420
	(abaxial)	**Larvae**	A 7,3	A 9,7	A 12,0	A 8,3	0,53	0,674
	(abaxial)	**Nymphs**	A -1,1	A -1,0	A 2,2	A 0,0	1,99	0,195
	(abaxial)	**Adults**	A 0,5	A -0,1	A 0,7	A 0,1	1,47	0,295
Exp.no	**Leaf #:**	**Life-stage:**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6	**(axial)**	**Eggs**	A 26,8	A 6,9	A 19,7	A 17,2	2,40	0,143
	(axial)	**Larvae**	B 8,8	B 11,2	A 17,4	A 17,1	14,7	0,001
	(axial)	**Nymphs**	B 2,1	B 2,2	A 12,9	A 12,3	21,14	0,000
	(axial)	**Adults**	A 0,0	A 0,4	A -0,0	A 0,1	0,25	0,862
	(abaxial)	**Eggs**	A 15,3	A 14,9	A 8,2	A 6,4	1,52	0,282
	(abaxial)	**Larvae**	A 6,0	A 4,0	A 11,5	A 10,2	3,58	0,066
	(abaxial)	**Nymphs**	A 1,2	A 0,9	A 3,2	A 5,5	2,45	0,139
	(abaxial)	**Adults**	A -0,2	A -0,1	A -0,3	A -0,2	0,11	0,954

In experiment 5 and 6, where counting was done on both sides of the leaves. The green LED lights had no significant effect on the axial-abaxial distribution of mites. Meaning that no significant positive phototaxis toward the axial side of the leaf contra abaxial was detected (table 15). The natural preference that *T. urticae* has towards living on the abaxial side of the leaf could not be detected in any of the experiments either. The only notable result from comparison of axial percentages was that there were significantly less dead mites on top of the leaf compared to the bottom side during the registration of first leaves in experiment 6 (table 15).

Table 125.Mean percentage of mites on the axial side of the leaves in the last registration of experiment 5 and in experiment 6. Life-stages are pooled and divided by treatments. Letters (A, and B) show statistical grouping, letters not shared with control are significant.

	Treatments					
Experiment No. (leaf. No.)	**UV + Green LED**	**UV**	**Green LED**	**Control**	**F-value**	**P-value**
5 (leaf 2) alive	A 47,5	A 36,3	A 50,4	A 56,8	18,80	0,377
5 (leaf 2) dead	A 71,4	A 61,2	A 52,1	A 49,8	0,72	0,570
5 (leaf 2) total (alive + dead)	A 50,6	A 38,9	A 50,6	A 56,5	0,79	0,534
Experiment No. (leaf. No.)	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6 (leaf 1) alive	A 37,7	A 47,5	A 42,5	A 45,4	0,73	0,563
6 (leaf 1) dead	B 37,4	A 84,7	AB 64,5	A 80,5	7,15	0,012
6 (leaf 1) total (alive + dead)	B 37,6	A 65,8	AB 43,6	AB 47,6	4,96	0,031
6 (leaf 2) alive	A 58,5	A 52,7	A 64,3	A 64,8	0,73	0,562
6 (leaf 2) dead	A 60,8	A 61,7	A 55,6	A 48,6	0,48	0,704
6 (leaf 2) total (alive + dead)	A 58,6	A 56,6	A 63,7	A 63,9	0,31	0,818

Temperature and relative humidity

The average temperature was almost constant across all experiments but varied somewhat in the 1st and 3rd quartile temperatures (figure 18). Temperature variability seem to be independent of any significant mortality results (table 8 – 9). The high relative humidity measurements logged during experiment 2-3 and 5-6, were caused by technical problems with the sensors. When compared to neighboring rooms with same RH settings, the mean relative humidity was closer to 65% in these periods.

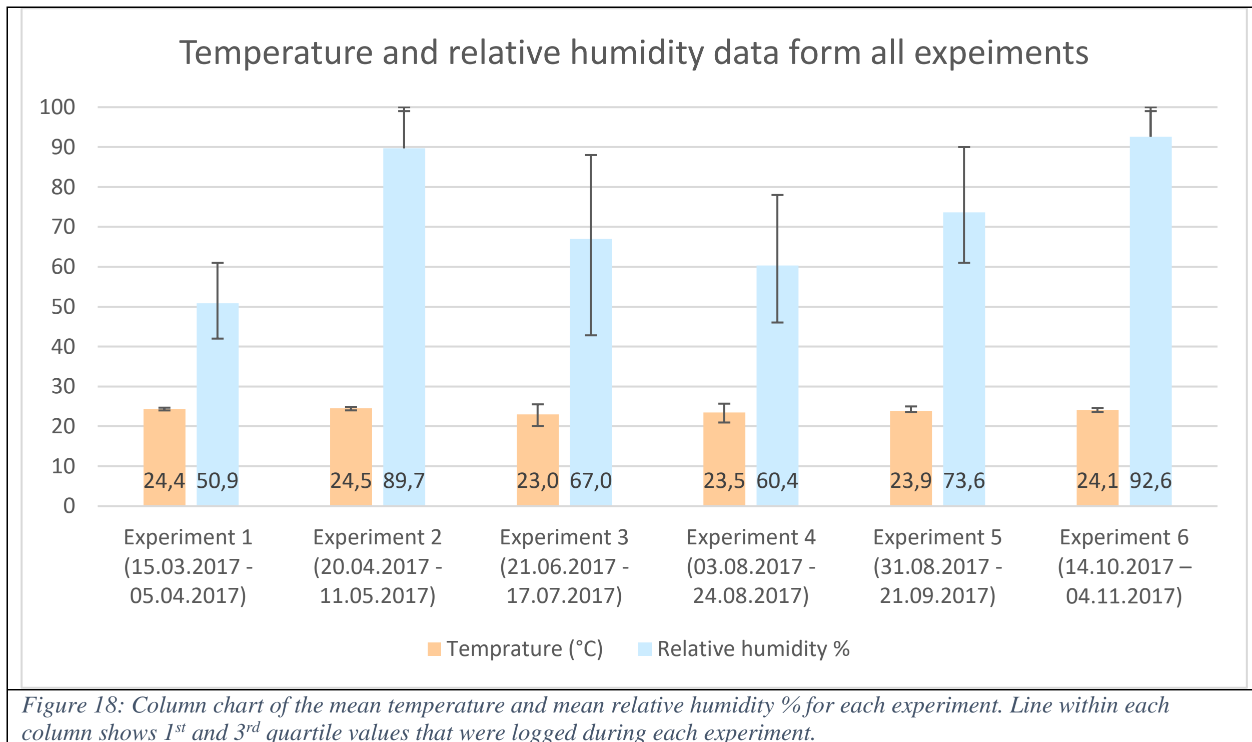


Figure 18: Column chart of the mean temperature and mean relative humidity % for each experiment. Line within each column shows 1st and 3rd quartile values that were logged during each experiment.

Additional comments

In the first experiment, plants were regularly cut as new shoots grew and were given nutrient solution. This resulted in some leaf necrosis and what seemed like nutrient accumulation. Plants within the UV treatments seemed to be affected more than non-UV treated plants (figure 19). Experiment 2 – 6 were much more successful in regard to the condition of the plants health (figure 20 A and B). In all experiments, the UV treated plants showed somewhat reduced growth, leaves had a darker color and were more brittle compared to non-UV treated plants (figure 20 A and B), the phenotypic difference did not seem to consistently affect neither the number of mites/cm^2, nor the change from the first to second leaves.

Figure 19. Ten days after start of experiment 1, example illustrating how plants reacted to excess cutting combined with nutrient solution (reflector and UV treatment).

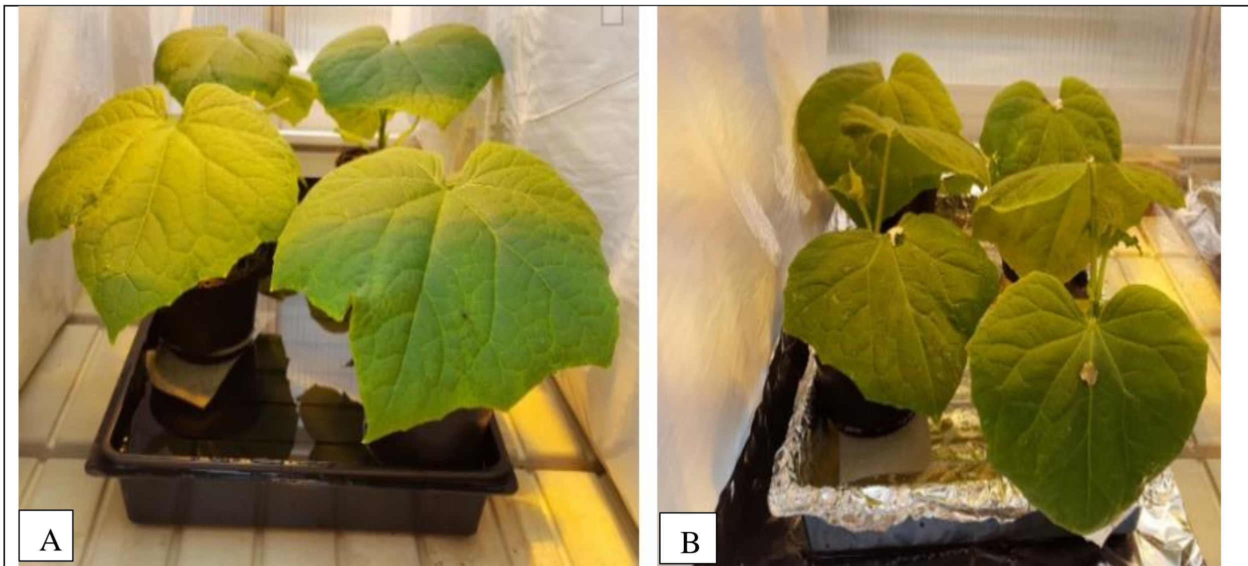


Figure 20. Example of how plants looked in experiment 2 (representative for experiment 2-6). Picture A represents a control treatment, while picture B represents plants from a treatment using reflectors and UV.

Discussion

UV radiation increased the mortality of *T. urticae* consistently across most of the experiments, the effect relied on the mites being exposed to the radiation. Consistent with literature (Johansen et al. 2017; Murata & Osakabe 2013), the life-stages of *T. urticae* most sensitive to UV damage were eggs, larvae and nymphs. The two factors which were included to increase UV exposure were reflectors and green LED lights. The treatment combinations which seemed most effective at exposing and killing mites were UV + reflector and UV + reflector + green LEDs. The common factor between these treatments was the utilization of reflectors underneath the plants. Under natural conditions *T. urticae* spend most of their lives on the abaxial side of the leaves thereby evading the deleterious effects of UV-B (Ohtsuka 2009). This is likely to be the reason why the use of UV in combination with reflectors gave consistently significant mortality across most experiments. However, axial-abaxial ratios of mite distribution in experiments 5 (leaf 2) and 6 did not reflect this natural preference to staying on the abaxial side.

In experiment 4 and 5, the results from the UV + green LED treatment had no effect on mortality on the abaxial side of leaves. The mites on the axial side of the second leaves in experiment 5, had sustained significant mortality when life-stages were pooled within the UV + green LED treatment. When life-stages were compared separately the results showed that the mortality had mainly occurred within the nymph stages. Although there was one significant mortality result within the UV + green LED treatment in experiment 5, most of mortality sustained in experiment 4 and 5 was in the treatment using only UV. Treatments which included green light did not attract mites to the axial side of leaves in experiment 5 or 6. This could be caused by the high intensity of green light used in these experiments (17,11 ± 2,28 W/m^2) allowing for transmittance of green light through the leaves, making any eventual positive phototaxis towards the axal side irrelevant. Suzuki et al. (2013) found that the sensitivity and positive phototaxis towards green light worked on even low intensities, down to 0.2 W/m^2. The reason plants are green, is because chlorophyll a and b absorbs very little green light (Mackinney 1941). Most of the green light from sunlight is either reflected or transmitted through the leaves, due to a gap in the absorbance of chlorophylls between the wavelengths 500 nm and 600 nm (Woolley 1971). The high intensity of the green light used in these experiments would have led to a substantial proportion of the irradiance being transmitted through the leaves. This could have nullified the supposed

effect of attracting mites to the axial side of the leaf, and instead led to some sort of stimulatory phototaxis effect wherever the mite would have been located. This would explain why the green light had no effect on the axial-abaxial distribution of mites. The strong phototactic effect that green light has on *T. urticae* according to Suzuki et al. (2013), would also provide a plausible explanation for how the treatment using all variables (UV + green LED + reflector) could be more effective than the UV and reflector treatment in the last experiment. The green LED lights transmitting through the leaves could prompt a phototactic reaction which could cause mites to be more active on both sides of the leaves during the UV period (Johansen et al. 2011), thereby increasing their exposure, as opposed to staying still in UV shaded areas.

Under natural conditions, *T. urticae* cope with the high amount of UV-B present in sunlight in two ways; they avoid it by living on the abaxial side of leaves (Ohtsuka 2009), and if DNA damage occurs, it is repaired via photoreactivation and other ROS scavenging antioxidants (Murata & Osakabe 2013; Murata & Osakabe 2014). *Tetranychus urticae's* genome has been sequenced and revealed several novel attributes, genetic elements related to their polyphagous ability, resistance to acaricides and photoreactivation (Grbić et al. 2011). Several cyclobutene pyrimidine dimer photolyase genes were discovered, these enables *T. urticae* to repair a lot of the DNA damage caused by UV-B radiation. Photolyase enzymes are able to reverse DNA damage by utilizing visible light (especially blue and green) and UV-A (Murata & Osakabe 2014). The photoreactivation ability of *T. urticae* is demonstrated by the gap between lethal cumulative dose of UV-B under lab- (UV-B) and field (sunlight) conditions. In field conditions the lethal dose for *T. urticae* eggs is more than >80 times higher than what has been documented in lab conditions (Murata & Osakabe 2013; Sakai et al. 2012). The UV lamps used in the current experiments contained both UV-A and UV-B (figure 5). The addition of green light may also have affected *T. urticae*'s photolyase ability, as the green LED exposure overlapped the entire duration of the UV exposure (Koveos et al. 2017).

The vision of non-diapausing *T. urticae* female's, peak in the UV-A and UV-B parts of the light spectrum while also showing some sensitivity towards green light (Naegele et al. 1966; Suzuki et al. 2013). But the difference between their sensitivity towards UV compared to green light is quite large. Suzuki et al. (2013) theorized that for *T. urticae* to effectively photo-orientate to the

abaxial side of leaves under natural conditions, they need sensitivity to both UV and Green light. If the mites only orientated by negative phototaxis away from UV, the majority would have a tough time ending up on the abaxial side versus any other shaded place on the plant. Conversely, if they only orientated by attraction to visible or green light, the probability of UV damage would be very high. Hence, their vision is selected towards having the highest sensitivity towards UV because it has the highest risk involved with being exposed to it, while green light works as a que which indicates to the mite that it is on the abaxial side of the leaf. In other words, if a mite is exposed to both green and UV, it should react to the UV rather than the green light. As explained the UV lamps used in these experiments used 1-minute to heat up before reaching peak intensity, this could have provided mites enough time to react phototactically and move away from UV exposed areas.

Under natural conditions plants filter out the UV in sunlight before it reaches the chloroplasts. The first response plants use to limit UV damage usually involves the production of phenolics, such as flavonoids, and increasing leaf thickness (Murata & Osakabe 2014; Suzuki et al. 2013; Vänninen et al. 2010; Woolley 1971). Results from both alive/cm^2 and total mites/cm^2, showed there was significantly more mites in the two first experiments within the UV treatment. In the second experiment this could be an effect of plants being stressed by the UV radiation, thereby expending too much of available nutrients on protection against UV, resulting in plants becoming more susceptible to *T. urticae* (Larsson 1989). For experiment 1, it is more difficult to discern the cause of the increase in mite numbers in the UV treatment, as plants were given nutrient solution and should therefore not have been limited by resources. A possible explanation might be that the darker leaf color of the UV treated plants caused the temperature on the abaxial side of the leaves to rise during daytime, thereby increasing population growth of *T. urticae*. Similarly, for the significant increase in the number of alive nymphs/cm^2 in the reflector treatment seen in experiment 1, heat may have been the cause of increased productivity (Malais & Ravensberg 2004). The rest of the notable results in alive mites/cm^2, were all significantly lower than control and were most likely caused by either direct mortality from UV or reduced egg laying capacity due to UV exposure (Koveos et al. 2017).

UV treated plants consistently displayed photomorphogenic differences compared to plants in other treatments (figure 21). However, this did not reduce the total (alive and dead) number of mites observed in experiment 1-5. In experiment 6 however, there were significantly less larvae and nymphs in both UV treatments, while all but one of the noteworthy results in experiment 6 were on the axial side of the leaf. This could be an effect of higher intensity UV light on the axial side of the leaf, causing the mites to prefer the abaxial side. But this would have affected the axial-abaxial ratio, which it did not. The reduced number of mites is therefore most likely caused by the high mortality occurring within the same treatments in experiment 6. Alternatively, the reduction could be caused by plant mediated effects (Vänninen et al. 2010), or reduced egg-laying capacity induced by UV-B exposure, as was found in other studies (Koveos et al. 2017; Murata & Osakabe 2013; Ohtsuka 2009). Generally, the plants in the UV treatments had the following symptoms; leaves were darker green in color (figure 21 A), some reduced leaf and stem growth, less springy and more brittle leaves, sometimes with furled edges. Most of these symptoms correlate with what is found in literature (Hemantaranjan 2016; Tevini et al. 1983; Vänninen et al. 2010), relating to stress response caused by UV-B radiation. The darker color in the leaves were probably caused by an increase in the UV-B absorbing pigment flavonoid and increased leaf thickness, the brittleness of leaves could be linked to changes in the production of cuticular waxes and leaf thickness. It is common that plants exposed to relatively high levels of UV-B have some reduction in photosynthetic activity which in turn would affect transpiration causing reduced growth, and leaf expansion (Hemantaranjan 2016).

Figure 21. Picture A and B is from the first registration of experiment 6, picture A is from a UV + reflector + green LED treatment and picture B is from a control treatment.

In the current experiments, short “bursts” of nighttime UV exposure was used on plants that had grown two true leaves. But as Vänninen et al. (2010) suggests, plants adapt to their spectral environment, the adaptivity increases if they are exposed from an earlier age. Exposing host-plants to continuous UV from seedling stage could increase both photomorphogenic and photochemical effects. this could potentially cause greater plant mediated effects on the pest population, while also increasing plants resistance to UV. Since *T. urticae, P. aphanis* and *G. biocellatus* all are subject to BRL when exposed to UV-B (Murata & Osakabe 2013; Suthaparan et al. 2016b), it would be interesting to see the effect of low intensity UV-B over a longer duration. This would allow the plants more time to adapt to the radiation while also causing direct and indirect mortality in the pest-population. Hemantaranjan (2016) explored the use of the triazole compound hexaconazole (HEX) in combination with UV-B exposure. HEX is usually used as a broad-spectrum fungicide which causes morphological, biochemical and hormonal changes in plants. When tested on cucumbers, HEX reduced growth parameters, but increased antioxidant activity, leaf thickness, flavonoid- and anthocyanin content. Thereby affecting the amount of both induced- and scavenged ROS in plant tissues, enhancing the plants ability to cope with UV-B radiation.

Mites killed or damaged by UV changed color to brown-orange and often lost internal pressure (figure 22 A, C and D), abnormally shaped larvae and eggs were also frequently occurring symptoms (figure 22 B and D). The sequencing of *T. urticae’s* genome has revealed many horizontally transferred gene elements from both bacteria and funguses (Grbić et al. 2011). Many of these genes have been tied to *T. urticae*’s polyphagous ability and the development of resistance against acaricides. But two gene clusters related to the biosynthesis of carotenoids was also discovered, these genes are homologous to genes also found in *zygomycete* and aphids (Altincicek et al. 2012; Grbić et al. 2011). The genes are characteristically expressed in diapausing females of *T. urticae*, giving them their orange color. But Altincicek et al. (2012) also found them expressed in both green- and red morphs of non-diapausing individuals. Although red morphs of *T. urticae* show a significantly higher expression of these genes, the ability is also present in non-diapausing green morphs. The effectiveness of chemical control of *T. urticae* is limited by *T. urticae*’s genome adaptability in detoxifying, its reproductive system and rapid development. Using UV-B represents an alternative method of attack in controlling *T. urticae*,

but the question remains whether it is sustainable over time, or if *T. urticae* will simply be selected in favor of higher carotenoid production (e.g. red morphs) which would reduce the effectiveness of UV-B radiation.

Figure 22. Example of how mites killed by UV looked. Picture A is of a dead larva, Picture B is of a mite killed while in protochrysalis stage. Picture C is of a healthy and a UV damaged deutonymph (brown-orange), Picture D is of healthy and UV damaged egg (orange, disformed)

When comparing the mortality results for each life-stage between UV and UV + green LED treatment in experiment 4, it seems there was either plant mediated effects or increased carotenoid production occurring respectively. The mortality in the UV treatment occurred on the abaxial side of the leaf, where exposure to UV should not have occurred. The cause of this may be that the mites were exposed to a lethal dose of UV on the axial side of the leaves, but had sufficient time to respond to the negative phototaxis, moving to the abaxial side of the leaf before death occurred. Since the same results did not occur in the UV + green LED, this could mean that photoreactivation was occurring. Recently, Koveos et al. (2017) conducted experiments to

compare egg hatchability after direct, continuous exposure of eggs to different LED treatments. They compared eggs from *T. urticae* and four predatory mites; *Amblyseius swirskii* (Athias-Henriot)*, Iphiseius degenerans* (Berlese)*, Euseius finlandicus* (Oudemans) and *Phytoseiulus persimilis* (Athias-Henriot). The types of LEDs they used were visible white light (4,5 W/m^2) and UV-B, testing different doses of UV-B (0,9 – 4,3 KJ/m^2/day) both with and without simultaneous exposure to white light. Their results showed that if UV-B was provided simultaneously with white light, *T. urticae* eggs were able to withstand significantly higher doses (50 % hatchability, 2.5 kJ /m^2/day) of UV-B due of their photoreactivation system. However, when solely using UV-B without simultaneous exposure to white light, they found *T. urticae* to be the most vulnerable amongst the compared species. This photoreactivation system would explain the significant mortality difference seen in experiment 4, between the UV and UV + Green LED treatment. The green LED lights fully overlapped with the UV exposure and the intensity of the green LED lamps was substantially higher (17,1 ± 2,3 W/m^2) and the UV considerably lower (0,29 ± 0,04 kJ /m^2/day) than what Koveos et al. (2017) used. However, photoreactivation does not seem to have been influenced by the green light when comparing the UV treatments in experiment 6. Murata and Osakabe (2014) found that if visible light was delayed by ≥4hours after UV exposure, photoreactivation became negligible. But the lowest time-lag they tested was immediately after UV exposure, not simultaneous. While Koveos et al. (2017) used both UV and visible white light simultaneously and continuously over 2-5 days. It could be that the overlap between the green LED lights and UV exposure did not affect photoreactivation, as the UV dose was delivered as a short 3-minute "burst" and the green LEDs turned off simultaneous with the UV light. It seems that photoreactivation did not have time to occur or cause a significant effect in experiment 6. Furthermore, the mortality results from the UV treatment in experiment 4 were fairly low when compared to other treatments which inflicted significant mortality. When comparing the results of the UV treatment in experiment 4 to the same treatment from experiment 1-3, it is well within the variation range which occurred.

Since the biochemical contents of neither mites nor plants were measured, it is difficult to distinguish whether there were either plant-mediated effects or changes in carotenoid production in mites occurring which may have influenced the results. In experiment 6, the total amount mites/cm^2 was lower in the UV treatments, which might point to plant mediated effects, but it is

most likely caused by the mortality in the same treatments leaving less reproducing individuals. Alternatively, the effect could be caused by a decreased egg-laying capacity because of exposure to UV-B (Koveos et al. 2017). When comparing either total amount of mite/cm^2 (per life-stage), alive mites/cm^2 or mortality results for experiment 6, there is consistently no indication of photoreactivation occurring in the UV + reflector + green LED treatment. On the contrary, it seems the treatment was more effective than the UV + reflector treatment across all parameters measured. Though it is worth noting that the UV + reflector + green LED was only conducted in one experiment, while UV + reflectors were included in four experiments and affected mortality consistently in each.

The potential of using UV-B radiation as an IPM tool in greenhouse production is considerable, it represents an innovative approach to combating a wide range of different pests which have generally been controlled with either chemicals or biocontrol agents. The development of new LED technology's that can produce highly specific wavelengths, opens new opportunities for further research. Commercial use LEDs in controlled environment agriculture (CEA) is still somewhat limited by the high economical cost of these technologies. But the future looks bright for LEDs, every decade LED performance is increased by a factor of twenty while the prices drop by a factor of ten, this development is referred to as Haitz's law (Morrow 2008). LEDs potential in modifying the spectral composition of indoor production systems can produce specie-specific effects (Johansen et al. 2011), because different wavelengths can elicit distinct behavioral responses in various arthropod species. The amount of research being done on how to use light to affect pest populations is extensive, but is still in the early phases of considering how all the trophic levels in CEA systems are affected by its use. More research is still needed on how the visual ecology of pests and biocontrol agents are affected by different lighting technologies. A few of the many advantages of using LED light compared to conventional broad-spectrum HPS lamps, is that LEDs can reach peak intensity instantaneously, are wavelength specific and give of very little heat radiation which allow for effective inter-lighting without harming plants. These attributes allow for new ways of manipulating photoperiod, affecting the behavior of pests and biocontrol agents, influencing the production of defensive compounds in plants or directly harming pest populations (Johansen et al. 2011).

I would suggest further research be conducted in the following; fractionated high intensity UV-B of *T. urticae* with multiple exposure events each night to see the effect of direct harmfulness coupled with disruption of photoperiods (Johansen et al. 2011). Continuous low intensity UV-B radiation on plants from seedling stage would allow for plants to adapt to higher doses of UV-B while increasing plant-mediated effects (Vänninen et al. 2010). Since *T. urticae* is subject to BRL this would cause mortality and could be combined with night-time burst exposure of UV-B. Experiments with UV-B LEDs should be compared to UV lamps equivalent to the ones used in these experiments, to elucidate any potential photoreactivation affected by the UV-A given-off by the UV fluorescent tubes. The biochemically content of both plants and *T. urticae* should be analyzed in a similar experiment setup, to quantify eventual increases in defensive plant compounds or changes in mites' ROS defense system (Koveos et al. 2017). Investigate the potential compatibility of substances such as triazole compounds and UV-B, since these can mitigate UV-B damage in plants (Hemantaranjan 2016). Since the UV treated plants showed some reduced growth in comparison to non-UV treated plants, any effects of reduced yield from plants need to be compared to the positive effects of reducing pests, such as *T. urticae*.

Conclusion

Ultraviolet radiation can be used as an effective non-chemical approach to suppress *T. urticae* populations in CEA systems. The effectiveness depends on mites being exposed and the dose they receive. In these experiments the combinations of UV + reflector and UV + reflector + green LED were most effective at reducing mite populations. Egg-, larvae- and nymph stages were most susceptible to the deleterious effects of UV. The green LEDs were unsuccessful in luring mites to the axial side of leaves, but seemed to cause a phototactic response on both sides of the leaves, probably due to the high intensity of the green LEDs (17,11 ± 2,28 W/m^2). The axial-abaxial distribution did not change in response to any of the experiment variables which were included, nor was there a detectible preference in mites towards staying on the abaxial side of the leaves. The addition of green LED light to the UV + reflector treatment increased both mortality and substantially reduced the number of alive mites per cm^2. The short overlap between UV exposure and green LED light used in the current experiments, did not seem to influence photoreactivation in *T. urticae*.

Bibliography

Altincicek, B., Kovacs, J. L. & Gerardo, N. M. (2012). Horizontally transferred fungal carotenoid genes in the two-spotted spider mite Tetranychus urticae. *Biology letters*, 8 (2): 253-257.

Attia, S., Grissa, K. L., Lognay, G., Bitume, E., Hance, T. & Mailleux, A. C. (2013). A review of the major biological approaches to control the worldwide pest Tetranychus urticae (Acari: Tetranychidae) with special reference to natural pesticides. *Journal of Pest Science*, 86 (3): 361-386.

de Kogel, W. J., van der Hoek, M., Dik, M. T. A., Gebala, B., van Dijken, F. R. & Mollema, C. (1997). Seasonal variation in resistance of chrysanthemum cultivars to Frankliniella occidentalis (Thysanoptera: Thripidae). *Euphytica*, 97 (3): 283-288.

Fasulo, T. R. & Denmark, H. A. (2000). Two-spotted spider mite, Tetranychus urticae Koch. *UF/IFAS Featured Creatures EENY-150*.

Grbić, M., Van Leeuwen, T., Clark, R. M., Rombauts, S., Rouzé, P., Grbić, V., Osborne, E. J., Dermauw, W., Ngoc, P. C. T. & Ortego, F. (2011). The genome of Tetranychus urticae reveals herbivorous pest adaptations. *Nature*, 479 (7374): 487.

Hemantaranjan, A. (2016). *Advances In Plant Physiology Vol. 16*. 473 pp. 200-204

Jeppson, L. R., Keifer, H. H. & Baker, E. W. (1975). *Mites injurious to economic plants*: Univ of California Press.

Johansen, N. S., Vänninen, I., Pinto, D. M., Nissinen, A. I. & Shipp, L. (2011). In the light of new greenhouse technologies: 2. Direct effects of artificial lighting on arthropods and integrated pest management in greenhouse crops. *Annals of Applied Biology*, 159 (1): 1-27.

Johansen, N. S., Asalf B, S. A., Stensvand, A., J., F. P., Grimstad, L. & Gadoury, D. M. (2017, 5-9 August). *Nighttime treatments of ultraviolet (UV) light targeting powdery mildews also suppress the two-spotted spider mite (Tetranychus urticae).* Annual meeting of the American Phytopathological Society (APS), San Antonio, Texas.

Koveos, D. S., Suzuki, T., Terzidou, A., Kokkari, A., Floros, G., Damos, P. & Kouloussis, N. A. (2017). Egg hatching response to a range of ultraviolet-B (UV-B) radiation doses for four predatory mites and the herbivorous spider mite Tetranychus urticae. *Experimental and Applied Acarology*, 71 (1): 35-46.

Larsson, S. (1989). Stressful times for the plant stress: insect performance hypothesis. *Oikos*: 277-283.

Mackinney, G. (1941). Absorption of light by chlorophyll solutions. *J. biol. Chem*, 140 (2): 315-322.

Malais, M. H. & Ravensberg, W. J. (2004). *Knowing and recognizing, the biology of glasshouse pests and their natural enemies*: Koppert B.V.

Mazza, C. A., Zavala, J., Scopel, A. L. & Ballaré, C. L. (1999). Perception of solar UVB radiation by phytophagous insects: behavioral responses and ecosystem implications. *Proceedings of the National Academy of Sciences*, 96 (3): 980-985.

Mazza, C. A., Izaguirre, M. M., Zavala, J., Scopel, A. L. & Ballaré, C. L. (2002). Insect perception of ambient ultraviolet-B radiation. *Ecology Letters*, 5 (6): 722-726.

Morrow, R. C. (2008). LED lighting in horticulture. *HortScience*, 43 (7): 1947-1950.

Murata, Y. & Osakabe, M. (2013). The Bunsen–Roscoe reciprocity law in ultraviolet-B-induced mortality of the two-spotted spider mite Tetranychus urticae. *Journal of Insect Physiology*, 59 (3): 241-247.

Murata, Y. & Osakabe, M. (2014). Factors affecting photoreactivation in UVB-irradiated herbivorous spider mite (Tetranychus urticae). *Experimental and Applied Acarology*, 63 (2): 253-265.

Naegele, J. A., McEnroe, W. D. & Soans, A. B. (1966). Spectral sensitivity and orientation response of the two-spotted spider mite, Tetranychus urticae Koch, from 350 mμ to 700 mμ. *Journal of insect physiology*, 12 (9): 1187-1195.

Ohtsuka, K. (2009). Deleterious effects of UV-B radiation on herbivorous spider mites: they can avoid it by remaining on lower leaf surfaces. *Environmental entomology*, 38 (3): 920-929.

Onzo, A., Sabelis, M. W. & Hanna, R. (2010). Effects of ultraviolet radiation on predatory mites and the role of refuges in plant structures. *Environmental entomology*, 39 (2): 695-701.

Patterson, C. G., Archbold, D. D., Rodriguez, J. G. & Hamilton-Kemp, T. R. (1994). Daylength and resistance of strawberry foliage to the twospotted spider mite. *Hortscience*, 29 (11): 1329-1331.

Sakai, Y. & Osakabe, M. (2010). Spectrum-specific Damage and Solar Ultraviolet Radiation Avoidance in the Two-spotted Spider Mite. *Photochemistry and Photobiology*, 86 (4): 925-932.

Sakai, Y., Sudo, M. & Osakabe, M. (2012). Seasonal changes in the deleterious effects of solar ultraviolet-B radiation on eggs of the twospotted spider mite, Tetranychus urticae (Acari: Tetranychidae). *Applied entomology and zoology*, 47 (1): 67-73.

Sato, M., et al. (2016). Tetranychus urticae, shown resistance to active ingredient(s). In https://www.pesticideresistance.org/. IRAC. http://www.irac-online.org/ online database (Atrhropod Pesticide Resistance Database). Available at:

https://www.pesticideresistance.org/display.php?page=species&arId=536 (accessed: 12.09.2017).

Schindl, B., Rosado-Schlosser, F. & Trautinger, F. (2011). *The reciprocity rule in photobiology - a review*. http://www.photobiology.com: Department of Dermatology, Division of Special and Environmental Dermatology, University of Vienna Medical School. Available at: http://www.photobiology.com/reviews/bunsen/ (accessed: 13.09.2017).

Sudo, M. & Osakabe, M. (2011). Do plant mites commonly prefer the underside of leaves? *Experimental and Applied Acarology*, 55 (1): 25-38.

Suthaparan, A. (2010). *Use of supplemental lighting towards efficient management of powdery mildew in greenhouse roses*: Norwegian University of Life Sciences, Department of Plant and Environmental Sciences.

Suthaparan, A., Stensvand, A., Solhaug, K. A., Torre, S., Telfer, K. H., Ruud, A. K., Mortensen, L. M., Gadoury, D. M., Seem, R. C. & Gislerød, H. R. (2014). Suppression of cucumber powdery mildew by supplemental UV-B radiation in greenhouses can be augmented or reduced by background radiation quality. *Plant Disease*, 98 (10): 1349-1357.

Suthaparan, A., Solhaug, A. K., Stensvand, A. & Gislerød, H. R. (2016a). Determination of UV action spectra affecting the infection process of Oidium neolycopersici, the cause of tomato powdery mildew. *Journal of Photochemistry and Photobiology B: Biology*, 156: 41-49.

Suthaparan, A., Solhaug, K. A., Bjugstad, N., Gislerød, H. R., Gadoury, D. M. & Stensvand, A. (2016b). Suppression of powdery mildews by UV-B: application frequency and timing, dose, reflectance, and automation. *Plant Disease*, 100 (8): 1643-1650.

Suzuki, T., Watanabe, M. & Takeda, M. (2009). UV tolerance in the two-spotted spider mite, Tetranychus urticae. *Journal of Insect Physiology*, 55 (7): 649-654.

Suzuki, T., Kojima, T., Takeda, M. & Sakuma, M. (2013). Photo-orientation regulates seasonal habitat selection in the two-spotted spider mite, Tetranychus urticae. *Journal of Experimental Biology*, 216 (6): 977-983.

Tachi, F. & Osakabe, M. (2012). Vulnerability and behavioral response to ultraviolet radiation in the components of a foliar mite prey–predator system. *Naturwissenschaften*, 99 (12): 1031-1038.

Tehri, K. (2014). A review on reproductive strategies in two spotted spider mite, Tetranychus Urticae Koch 1836 (Acari: Tetranychidae). *J Entomol Zool Stud*, 2: 35-39.

Tevini, M., Iwanzik, W. & Teramura, A. H. (1983). Effects of UV-B Radiation on Plants During Mild Water Stress II. Effects on Growth, Protein and Flavonoid Content. *Zeitschrift für Pflanzenphysiologie*, 110 (5): 459-467.

Vänninen, I., Pinto, D. M., Nissinen, A. I., Johansen, N. S. & Shipp, L. (2010). In the light of new greenhouse technologies: 1. Plant-mediated effects of artificial lighting on arthropods and tritrophic interactions. *Annals of applied biology*, 157 (3): 393-414.

Wargent, J. J. & Jordan, B. R. (2013). From ozone depletion to agriculture: understanding the role of UV radiation in sustainable crop production. *New Phytologist*, 197 (4): 1058-1076.

Woolley, J. T. (1971). Reflectance and transmittance of light by leaves. *Plant physiology*, 47 (5): 656-662.

Appendices

Appendix 1

The number of alive mites/cm^2 for each life-stage and pooled in every registration. Significant differences are colored.

		Treatment AMOUNT OF ALIVE MITES/CM2					
EXP no. Leaf no. (leaf side)	Life-stage:	UV + Reflector	UV	Reflector	Control	F-value	P-value
1.1 (Abaxial)	Eggs	A 5	A 3,6	A 4,4	A 2,1	2,65	0,120
1.1 (Abaxial)	Larvae	AB 1,2	A 2	B 0,9	B 1,1	6,62	0,015
1.1 (Abaxial)	Nymphs	A 1,2	A 2	A 1,5	A 1,6	2,22	0,163
1.1 (Abaxial)	Adults	B 0,9	AB 1,7	A 1,9	AB 1,3	4,70	0,036
1.1 (Abaxial) Pooled LS:		A 8,3	A 8,3	A 8,7	A 5,7	3,69	0,062
1.2 (Abaxial)	Eggs	B 29,7	AB 36,6	A 64,7	AB 42	4,26	0,045
1.2 (Abaxial)	Larvae	B 6,5	A 16,9	AB 13,4	AB 10,1	8,24	0,008
1.2 (Abaxial)	Nymphs	C 1,3	AB 4,5	A 5,6	BC 2,8	10,48	0,004
1.2 (Abaxial)	Adults	A 1,7	A 2,3	A 2	A 1,7	0,49	0,699
1.2 (Abaxial) Pooled LS:		A 30,9	A 70,0	A 57,3	A 51,1	1,75	0,233
2.1 (Abaxial)	Eggs	A 2,1	A 6,2	A 2,3	A 3,3	2,41	0,142
2.1 (Abaxial)	Larvae	B 0,4	A 1,6	B 0,5	B 0,7	29,87	0,000
2.1 (Abaxial)	Nymphs	B 0,7	A 2,2	B 0,8	B 1,0	7,76	0,009
2.1 (Abaxial)	Adults	C 0,3	A 1,4	BC 0,7	B 0,9	16,47	0,001
2.1 (Abaxial) Pooled LS:		B 3,4	A 11,4	AB 5,1	AB 5,8	4,69	0,036
2.2 (Abaxial)	Eggs	A 18,8	A 27,4	A 29,2	A 33,5	1,35	0,325
2.2 (Abaxial)	Larvae	B 4,1	AB 14,2	A 19,7	AB 14,8	6,47	0,016
2.2 (Abaxial)	Nymphs	A 2,8	A 7,5	A 7,8	A 5,6	2,45	0,138
2.2 (Abaxial)	Adults	A 1,2	A 1	A 1	A 1,6	3,46	0,071
2.2 (Abaxial) Pooled LS:		B 26,9	AB 50,1	A 57,7	A 55,4	6,50	0,015
3.1 (Abaxial)	Eggs	A 2,6	A 4,1	A 1,8	A 3,6	2,13	0,174
3.1 (Abaxial)	Larvae	B 0,2	A 1,2	AB 0,5	AB 0,8	4,15	0,048
3.1 (Abaxial)	Nymphs	B 0,7	A 2,7	B 0,8	AB 1,1	6,29	0,017
3.1 (Abaxial)	Adults	A 0,4	A 1,1	A 0,7	A 1,1	2,10	0,179
3.1 (Abaxial) Pooled LS:		A 3,9	A 9,1	A 3,7	A 6,6	3,24	0,082
3.2 (Abaxial)	Eggs	A 24,6	A 37,8	A 40,1	A 51,6	3,21	0,083
3.2 (Abaxial)	Larvae	B 3,9	A 15,4	A 21,5	AB 15,2	8,44	0,007
3.2 (Abaxial)	Nymphs	B 0,7	B 2,3	A 5,4	AB 3	9,06	0,006
3.2 (Abaxial)	Adults	A 0,5	A 1,0	A 1,7	A 1,0	2,33	0,150
3.2 (Abaxial) Pooled LS:		B 29,7	AB 56,6	A 68,7	A 70,7	5,86	0,020
EXP no. Leaf no. (leaf side)	Life-stage:	UV + Green LED	UV	Green LED	Control	F-value	P-value
4.1 (Abaxial)	Eggs	A 3,2	A 5,6	A 3,1	A 4,1	1,04	0,426
4.1 (Abaxial)	Larvae	A 0,4	A 0,7	A 0,4	A 0,5	0,57	0,653

4.1 (Abaxial)	**Nymphs**	A 1,8	A 2,5	A 1,1	A 1,6	2,47	0,137
4.1 (Abaxial)	**Adults**	A 0,7	A 0,8	A 0,5	A 0,8	1,26	0,350
4.1 (Abaxial) Pooled LS:		A 6,2	A 9,5	A 5,2	A 7,0	2,12	0,176
4.2 (Abaxial)	**Eggs**	AB 19,5	B 13,9	A 25,0	A 25,3	5,99	0,019
4.2 (Abaxial)	**Larvae**	AB 13,2	B 9,5	A 15,7	AB 13,6	4,87	0,033
4.2 (Abaxial)	**Nymphs**	A 5,3	A 7,6	A 7,3	A 5,0	3,31	0,078
4.2 (Abaxial)	**Adults**	A 0,4	A 0,8	A 0,7	A 0,8	1,37	0,319
4.2 (Abaxial) Pooled LS:		AB 38,4	B 31,8	A 48,7	A 44,7	10,30	0,004
5.1 (Abaxial)	**Eggs**	A 3,7	A 3,5	A 2,0	A 2,2	2,63	0,122
5.1 (Abaxial)	**Larvae**	A 1,7	A 1,8	A 1,3	A 1,2	1,86	0,215
5.1 (Abaxial)	**Nymphs**	A 4,5	A 5,2	A 3,9	A 3,6	1,45	0,300
5.1 (Abaxial)	**Adults**	A 0,9	A 1,0	A 1,1	A 1,5	0,82	0,519
5.1 (Abaxial) Pooled LS:		A 10,8	A 11,5	A 8,2	A 8,6	1,29	0,343
5.2 (Axial)	**Eggs**	A 10,3	A 7,4	A 15,3	A 20,7	0,82	0,517
5.2 (Axial)	**Larvae**	A 10,5	A 10,9	A 16,3	A 16,7	4,55	0,039
5.2 (Axial)	**Nymphs**	A 1,9	A 1,1	A 6,6	A 7,9	3,63	0,064
5.2 (Axial)	**Adults**	A 1,1	A 1,2	A 2,1	A 2,5	2,99	0,096
5.2 (Axial) Pooled LS:		A 23,9	A 20,6	A 40,2	A 47,8	4,16	0,047
5.2 (Abaxial)	**Eggs**	A 12,9	A 20,7	A 18,8	A 21,8	0,89	0,486
5.2 (Abaxial)	**Larvae**	A 8,7	A 11,2	A 13,1	A 9,3	0,47	0,711
5.2 (Abaxial)	**Nymphs**	A 3,2	A 4,1	A 6,0	A 3,6	0,71	0,572
5.2 (Abaxial)	**Adults**	A 1,3	A 0,8	A 1,8	A 1,4	2,34	0,150
5.2 (Abaxial) Pooled LS:		A 26,0	A 36,8	A 39,8	A 36,1	1,08	0,411

EXP no. Leaf no. (leaf side)	**Life-stage:**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**	**F-value**	**P-value**
6.1 (Axial)	**Eggs**	A 1,0	A 1,8	A 2,3	A 2,5	2,68	0,117
6.1 (Axial)	**Larvae**	A 0,8	A 0,5	A 1,3	A 1,5	3,82	0,057
6.1 (Axial)	**Nymphs**	AB 1,5	B 1,2	AB 2,4	A 2,6	7,01	0,013
6.1 (Axial)	**Adults**	A 0,8	A 0,4	A 0,9	A 0,9	1,13	0,395
6.1 (Axial) Pooled LS:		A 4,1	A 4,1	A 6,9	A 7,5	4,03	0,051
6.1 (Abaxial)	**Eggs**	AB 3,4	B 2,0	A 4,5	A 4,4	5,56	0,023
6.1 (Abaxial)	**Larvae**	A 0,7	A 0,5	A 0,6	A 0,6	1,37	0,320
6.1 (Abaxial)	**Nymphs**	A 2,0	A 1,6	A 3,3	A 2,9	2,84	0,106
6.1 (Abaxial)	**Adults**	A 0,7	A 0,7	A 1,0	A 1,1	3,61	0,065
6.1 (Abaxial) Pooled LS:		AB 6,7	B 4,7	A 9,3	A 9,0	6,2	0,018
6.2 (Axial)	**Eggs**	A 19,0	A 8,9	A 20,0	A 18,7	1,54	0,279
6.2 (Axial)	**Larvae**	B 7,3	B 8,2	A 18,5	A 18,6	23,3	0,000
6.2 (Axial)	**Nymphs**	B 3,1	B 2,2	A 15,2	A 14,7	41,79	0,000
6.2 (Axial)	**Adults**	A 0,8	A 0,6	A 0,8	A 0,8	0,4	0,759
6.2 (Axial) Pooled LS:		BC 30,2	C 20,3	A 54,5	AB 52,8	11,38	0,003
6.2 (Abaxial)	**Eggs**	A 13,9	A 11,1	A 10,9	A 9,2	0,31	0,819

6.2 (Abaxial)	**Larvae**	A 6,1	A 4,1	A 11,7	A 10,6	4,37	0,042
6.2 (Abaxial)	**Nymphs**	AB 3,0	B 2,3	AB 6,4	A 8,2	5,25	0,027
6.2 (Abaxial)	**Adults**	A 0,5	A 0,4	A 0,7	A 0,8	1,92	0,205
6.2 (Abaxial) Pooled LS:		A 23,5	A 17,9	A 29,7	A 28,8	1,03	0,428

Appendix 2

The number of total (alive + dead) mites/cm2 for each life-stage in every registration. Significant differences are colored.

			Treatments			
Exp.no	**Leaf #:**	**Life-stage:**	**UV + Reflector**	**UV**	**Reflector**	**Control**
1	**1.1 (Abaxial)**	**Eggs**	A 6	A 4,2	A 4,8	A 2,4
	1.1 (Abaxial)	**Larvae**	B 1,4	A 2,6	B 1,0	B 1,2
	1.1 (Abaxial)	**Nymphs**	B 1,3	A 2,4	B 1,5	AB 1,7
	1.1 (Abaxial)	**Adults**	B 1	AB 1,9	A 2	AB 1,4
	1.2 (Abaxial)	**Eggs**	A 33	A 38,4	A 65,9	A 42,7
	1.2 (Abaxial)	**Larvae**	B 7,2	A 17,7	AB 13,8	B 10,2
	1.2 (Abaxial)	**Nymphs**	B 1,6	A 4,9	A 5,7	AB 2,9
	1.2 (Abaxial)	**Adults**	A 2	A 2,5	A 2,2	A 1,9
2	**2.1 (Abaxial)**	**Eggs**	A 4,6	A 6,6	A 2,3	A 3,4
	2.1 (Abaxial)	**Larvae**	B 0,5	A 2,3	B 0,5	B 0,7
	2.1 (Abaxial)	**Nymphs**	B 0,7	A 2,3	B 0,8	B 1,0
	2.1 (Abaxial)	**Adults**	C 0,3	A 1,5	BC 0,7	B 0,9
	2.2 (Abaxial)	**Eggs**	A 31,3	A 33,9	A 30,7	A 34,7
	2.2 (Abaxial)	**Larvae**	B 4,7	AB 15,2	A 20,2	AB 15
	2.2 (Abaxial)	**Nymphs**	A 3,0	A 7,9	A 8	A 5,7
	2.2 (Abaxial)	**Adults**	A 1,5	A 1,1	A 1,2	A 1,8
3	**3.1 (Abaxial)**	**Eggs**	A 5,2	AB 4,2	B 1,8	AB 3,6
	3.1 (Abaxial)	**Larvae**	A 0,4	A 1,2	A 0,5	A 0,8
	3.1 (Abaxial)	**Nymphs**	B 0,7	A 2,8	B 0,8	AB 1,1
	3.1 (Abaxial)	**Adults**	A 0,4	A 1,1	A 0,7	A 1,1
	3.2 (Abaxial)	**Eggs**	A 31,5	A 39,5	A 40,2	A 52,4
	3.2 (Abaxial)	**Larvae**	B 4,5	AB 15,8	A 21,6	AB 15,3
	3.2 (Abaxial)	**Nymphs**	B 0,9	B 2,4	A 5,5	AB 3,2
	3.2 (Abaxial)	**Adults**	A 0,9	A 1,2	A 1,8	A 1
	Leaf #:	**Life-stage:**	**UV + Green LED**	**UV**	**Green LED**	**Control**
4	**4.1 (Abaxial)**	**Eggs**	A 3,6	A 6	A 3,3	A 4,3
	4.1 (Abaxial)	**Larvae**	A 0,4	A 0,8	A 0,4	A 0,5
	4.1 (Abaxial)	**Nymphs**	A 1,9	A 2,5	A 1,2	A 1,6
	4.1 (Abaxial)	**Adults**	A 0,8	A 0,9	A 0,6	A 0,8
	4.2 (Abaxial)	**Eggs**	A 19,9	A 15,8	A 25,2	A 25,7
	4.2 (Abaxial)	**Larvae**	AB 13,4	B 10,1	A 15,8	AB 13,7
	4.2 (Abaxial)	**Nymphs**	A 5,4	A 7,8	A 7,4	A 5,2
	4.2 (Abaxial)	**Adults**	A 0,5	A 0,9	A 0,9	A 0,9
5	**5.1 (Abaxial)**	**Eggs**	A 3,9	A 3,7	A 2,1	A 2,4
	5.1 (Abaxial)	**Larvae**	A 1,7	A 2	A 1,4	A 1,2
	5.1 (Abaxial)	**Nymphs**	A 4,6	A 5,3	A 3,9	A 3,7

	5.1 (Abaxial)	Adults	A 1	A 1,1	A 1,1	A 1,5
	5.2 (Axial)	Eggs	A 12,6	A 9	A 16,9	A 21,9
	5.2 (Axial)	Larvae	A 13,1	A 13,1	A 16,6	A 17,2
	5.2 (Axial)	Nymphs	A 2,3	A 1,7	A 2,3	A 8
	5.2 (Axial)	Adults	A 1,3	A 1,3	A 2,3	A 2,5
	5.2 (Abaxial)	Eggs	A 13,8	A 21,9	A 20,3	A 23,1
	5.2 (Abaxial)	Larvae	A 9,1	A 11,6	A 13,4	A 9,4
	5.2 (Abaxial)	Nymphs	A 3,5	A 4,3	A 6,2	A 3,7
	5.2 (Abaxial)	Adults	A 1,5	A 0,9	A 1,9	A 1,6
	Leaf #:	**Life-stage:**	**UV + Reflector**	**UV + reflector + green LED**	**Green LED**	**Control**
6	6.1 (Axial)	Eggs	B 1,4	A 8,5	B 2,7	B 3,3
	6.1 (Axial)	Larvae	A 1,1	A 1,1	A 1,4	A 1,6
	6.1 (Axial)	Nymphs	AB 1,7	B 1,4	AB 2,4	A 2,6
	6.1 (Axial)	Adults	A 0,9	A 0,4	A 0,9	A 0,9
	6.1 (Abaxial)	Eggs	A 4,4	A 3	A 4,5	A 4,5
	6.1 (Abaxial)	Larvae	A 0,9	A 0,6	A 0,6	A 0,7
	6.1 (Abaxial)	Nymphs	A 2,2	A 1,7	A 3,4	A 2,9
	6.1 (Abaxial)	Adults	A 0,7	A 0,7	A 1	A 1,1
	6.2 (Axial)	Eggs	A 28,2	A 15,4	A 22,3	A 20,5
	6.2 (Axial)	Larvae	B 9,8	B 12,3	A 18,8	A 18,7
	6.2 (Axial)	Nymphs	B 3,8	B 3,5	A 15,3	A 14,9
	6.2 (Axial)	Adults	A 0,9	A 0,8	A 0,9	A 1
	6.2 (Abaxial)	Eggs	A 19,7	A 17,8	A 12,8	A 10,9
	6.2 (Abaxial)	Larvae	A 6,9	A 4,7	A 12,8	A 10,9
	6.2 (Abaxial)	Nymphs	AB 3,3	B 2,6	AB 6,6	A 8,4
	6.2 (Abaxial)	Adults	A 0,5	A 0,6	A 0,7	A ,9

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway