Please cite this article as:

Jena M.K., Studnicki M., Michalska K. Preliminary studies on the efficacy of *Blattisocius mali* (Acari: Blattisociidae) against *Tyrophagus putrescentiae* (Acari: Acaridae) on cucumber plants. Journal of Plant Protection Research. DOI: 10.24425/jppr.2026.3360

Original article

Preliminary studies on the efficacy of *Blattisocius mali* (Acari: Blattisociidae) against *Tyrophagus putrescentiae* (Acari: Acaridae) on cucumber plants

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Received: May 29, 2026

Accepted: August 10, 2026

Pre-proof Publication: August 18, 2026

Responsible Editor: Jacek Twardowski

DOI: 10.24425/jppr.2026.3360

Abstract

The predatory soil mite *Blattisocius mali* (Oudemans) is highly efficient in controlling arthropod pests infesting stored flower bulbs and tubers. Still, its ability to control pests of crop plants has not been tested to date. This study aimed to assess whether *B. mali* could control *Tyrophagus putrescentiae* (Schrank) infesting young cucumber plants using two different methods of predator-prey release at two predator-prey ratios and varying observation frequencies. In one test, predators were released on plants on the same day as prey infestation at a 1:6.7 predator-prey ratio, while in the other test, predators were released after one day of prey infestation at a 1:33.3 ratio. The experiments were conducted under semi-natural conditions at 21-23°C, 16L/8D photoperiod, and 80 ± 10% RH. Each treatment was replicated eight times. When predators were released simultaneously with prey infestation at a 1:6.7 ratio, a 95.50% efficiency was observed after just two days. Conversely, releasing predators one day after the initial infestation at a 1:33.3 ratio achieved 99.48% efficiency after five days. This study indicated that *B. mali* was highly effective at reducing *T. putrescentiae* populations on young cucumber plants in both tests and may possibly be used as a practical alternative for managing acarid-mite pests infesting young cucumber plants. Further tests at a larger spatial scale under greenhouse and field conditions are necessary to confirm this.

Keywords: biological control, crop plant, effectiveness, Mesostigmata, mold mite

Introduction

Biological pest control is gaining increasing prominence as a key component of sustainable agriculture. While numerous species of natural enemies are effective in combating pests damaging a variety of crops (Kersten *et al.* 2022; Tiftikçi and Kasap 2022; Lopez 2023; Mukhametov *et al.* 2023), there remains a pressing need to identify new candidates, as existing natural enemies may not consistently perform effectively across all environmental conditions. Predatory soil mites remain relatively underutilized in biological control strategies. However, they offer several notable advantages over predators that inhabit above-ground parts of plants. Many of these soil mites also tolerate adverse environmental conditions, enhancing their potential to establish and persist across various crop systems (Beretta *et al.* 2022).

Predatory soil mites from the family Blattisociidae are promising biocontrol agents against a variety of arthropod and nematode pests. Some species within this family, including *Blattisocius tarsalis* (Berlese)*, B. keegani* (Fox)*, B. dentriticus* (Berlese)*,* and *B. mali* (Oudemans), have been studied extensively (Rivard 1962; Riudavets *et al.* 2002; Esteca *et al.* 2014; Kassem 2019; Abbas *et al.* 2020; Gallego *et al.* 2020; Michalska *et al.* 2023; Jena *et al.* 2024, 2025). *Blattisocius mali* is a generalist predator and has been reported in soil, on plants, in storage, or in association with rodents, birds, or vertebrate nests (Oudemans 1931; Petrova *et al.* 2004; de Moraes *et al.* 2015). This mite preys on various arthropod pests, including acarid mites, tetranychid mites, thrips, flies, and moths (Abbas *et al.* 2020; Gallego *et al.* 2020; Solano-Rojas *et al.* 2022; Asgari *et al.* 2023; Michalska *et al.* 2023; Jena *et al.* 2024, 2025, 2026). In addition to arthropod pests, it can feed on nematodes (Abbas *et al.* 2020). Recent studies by Jena *et al.* (2024, 2025, 2026) and Michalska *et al.* (2025) highlight the strong potential of *B. mali* to reduce *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) populations, underscoring its importance in integrated pest management strategies.

Acarid mites are omnivorous and commonly occur in stored food products and decaying organic materials. Many species are associated with various insects or reside within the nests of vertebrates (Zhang 2003). Although acarid mites are commonly mycophagous, some acarid mites of the genus *Tyrophagus* are facultatively phytophagous, causing economic damage to plants, including both ornamental flowers and vegetables cultivated in greenhouses (Zhang 2003). The *T. putrescentiae* poses a serious threat to cucurbit seedlings, gerbera, violet, orchid, kalanchoe, and the bulbs of hyacinth, lilies, or tulips (Zhang 2003; Łabanowski 2013). They also cause direct damage to soybean plants under a no-tillage system (Oliveira *et al.* 2007). Moreover, they can pose a threat to *in vitro* cultures used for the micropropagation of lily bulbs and anthurium plants (Czajkowska 2006; Murillo *et al.* 2021). They are primarily pests of cucumber seedlings, with the greatest risk starting from germination until the first true leaves expand. Infestations were commonly introduced with rice straw, rice chaff, or wheat straw bales used in greenhouses, after which mites dispersed onto cucumber seedlings. In seedlings at the stage of one to two true developing leaves, *T. putrescentiae* causes leaf discoloration and malformation as well as small feeding holes at the base of the leaf (Figure 1a). In young plants at the five- to six-true-leaf stage, they cause numerous, large, yellowish spots with severe tissue loss after infesting unfolded, expanding leaves (Figure 1b). In severe cases, they cause deformities in plants (Nakao 1991; Michalska K., unpublished). To combat problems associated with *T. putrescentiae*, environmentally friendly strategies, including biological control, which involves the exploration and evaluation of natural enemies, are essential to manage their populations effectively and sustainably.

Previous studies have shown that *B. mali* is highly promising in controlling arthropod pests infesting stored potato tubers and flower bulbs (Gallego *et al.* 2020; Solano-Rojas *et al.* 2022; Jena *et al.* 2026). Although *B. mali* has been reported occasionally on plants, such as the bark of apple trees and leaves of strawberry plants (Oudemans 1931; Petrova *et al.* 2004), there is no report on the efficiency of *B. mali* in controlling the pests of crop plants. This study aimed to investigate whether *B. mali* could control *T. putrescentiae* infesting young cucumber plants using two different methods of predator-prey release at two different predator-prey combinations and varying observation frequencies.

Materials and Methods

Rearing of prey and predator

The stock colony of *T. putrescentiae* reared on instant dry bakers' yeast was obtained from the mass-rearing facility at the Department of Plant Protection, Warsaw University of Life Sciences (WULS) in Warsaw, Poland (Michalska *et al.* 2023). The colony was multiplied and maintained on yeast pellets inside flasks placed in a desiccator in an incubator (MIR-154-PE, Japan) at 26°C and 75 ± 5% RH in complete darkness. Each colony was fed yeast pellets once a week and aerated three times a week.

The primary population of *B. mali* was obtained from the Department of Plant Protection, WULS, and maintained at various life stages of *T. putrescentiae* in wheat bran (Michalska *et al.* 2023). The rearing unit consisted of soaked foam platforms, covered with foil and placed in larger vessels filled with water. The populations of *B. mali* were maintained in a climatic room, at 21-23°C, 85 ± 10% RH, and 16L/8D cycle (Michalska *et al.* 2023).

The capacity of *Blattisocius mali* to control *Tyrophagus putrescentiae* infesting cucumber plants

Cucumber seeds of the cultivar 'Skierniewicki' were purchased from the market and initially placed on wet filter paper in a Petri dish (15 cm diameter) for germination. Once the seeds germinated, seedlings at one seedling/pot were carefully transplanted into pots, each measuring 11 cm in diameter and filled with vegetable peat (Lasland Sp. z o. o., Poland). The pots containing cucumber seedlings were then placed in a Sanyo Environmental Test Chamber (Panasonic MLR-350, Japan) at 23°C, 16L/8D cycle, and 85 ± 5% RH. Once the cucumber seedlings had developed their first pair of leaves, they were relocated to a glasshouse, where they remained until they had grown five to six leaves and were still in a vegetative stage, i.e., without flower buds emerging at the leaf nodes. Finally, the plants were transferred to a climatic room illuminated by natural light at 21-23°C, 16L/8D photoperiod, and 80 ± 10% RH. Potted plants were placed in broad containers partially filled with water before releasing the prey and predator on the plants to prevent their escape. Using this methodology, two subsequent tests were performed with eight treatment and eight control plants, all of which had the upper surface of three apical leaves that were still not fully expanded and were infested with motile *T. putrescentiae*. The treatment combination consisted of either of the plants with an 18:120 (1:6.7) predator-prey ratio for the first test, or with an 18:600 (1:33.3) predator-prey ratio for the second test. The tests also differed in the method used to infest the leaves with motile mold mites. At the 1:6.7 predator-prey ratio, predators were released on cucumber plants on the same day as prey infestation, while at the 1:33.3 ratio, predators were released after one day of prey infestation.

In the first test with a predator-prey ratio of 1:6.7, 120 *T. putrescentiae* motiles at 40 motiles/leaf were carefully applied on the upper surface of three unfolded leaves of each plant using a fine brush. In the test with a predator-prey ratio of 1:33.3, approximately 600 *T. putrescentiae* motiles at approximately 200 motiles/leaf were released on the upper surface of three leaves of each plant using a specialized method to obtain 'clean' *T. putrescentiae* on leaves, non-contaminated with yeast particles when selected from mass rearing. This method involved placing approximately 200 motiles at the center of a moist tissue paper disc, 2.5 cm in diameter, using a fine brush. The discs, at one disc/leaf, were then placed on the upper surfaces of three unfolding leaves, allowing the motiles to migrate onto the leaves while leaving behind the yeast powders on the tissue paper discs. In both tests, the same number of predators, i.e., 18 *B. mali* adults (14 females, 4 males) at nine adults/leaf, were released on two *T. putrescentiae* infested leaves of each cucumber plant in the same way. The predators were released on two infested leaves to study their dispersal from those leaves to other infested and uninfested leaves on the plant. *Blattisocius mali* females and males were randomly chosen from the colony and starved for 24 h on cucumber leaf rectangular platforms (2 cm length and 1 cm width) before being released on infested plants in both tests. Two leaf platforms, each containing nine starved *B. mali* (7 females, 2 males), were placed on two *T. putrescentiae* infested leaves of a cucumber plant. These leaf rectangles were cut from the cucumber leaves and placed singly just above a piece of plasticine at the center of a Petri dish (9 cm diameter) containing water (Michalska *et al.* 2024). In both tests, predators were released on eight potted plants, which served as treatment (T1 or T2), while eight other predator-free plants infested with *T. putrescentiae* served as control (K1 or K2). The control plants received the same handling, wet paper discs, leaf platforms, or brushing procedure. The number of *T. putrescentiae* (eggs and motiles) on the same leaf, i.e., the leaf on which *T. putrescentiae* motiles were released, and on other leaves, was recorded on the day when predators were released (i.e., day 0), and then after the 1st day of predator release and on subsequent days until the end of the trial. Additionally, the number of *B. mali* (eggs and motiles) on the same leaf on which the platform containing starved predators was placed, on other leaves, and on the platform was counted first 14 h after the release of *B. mali* motiles and then on the 1st day after release and on the following days until the end of the trial. The numbers of eggs and motiles of *T. putrescentiae* and *B. mali* were counted daily using an Olympus SZX 12 Zoom Stereo Microscope equipped with an Olympus Highlight 3100 cold light source. Great caution was exercised to avoid disturbing the mites or harming the plants during the counting process. When the number of *T. putrescentiae* dropped below, on an average of one motile per plant, observations were conducted for two more days, and the experiment stopped.

The mean numbers of eggs and motiles of *T. putrescentiae* and *B. mali* per plant, as well as the efficiency of *B. mali* in suppressing *T. putrescentiae* relative to the control, were analyzed using generalized linear mixed models (GLMMs) assuming a Poisson distribution with a log link function. For the analysis of egg and motile abundance, treatment, time, and their interaction were included as fixed effects. For the analysis of predator efficiency, treatment was included as a fixed effect and time as a random effect, following the approach proposed by Piepho *et al.* (2024). Because observations were repeatedly recorded over time, an autocorrelation variance–covariance structure was incorporated into all models to account for temporal dependence among repeated measurements. Pairwise comparisons of estimated marginal means were performed using Tukey's adjustment. Before model fitting, overdispersion was assessed using the Cameron and Trivedi dispersion test, and no evidence of overdispersion was detected. The data obtained from *T. putrescentiae* (eggs and motiles) during sampling were converted to cumulative mite-days (CMD) following the protocol described by Ruppel (1983) and Jena *et al.* (2026b). All tests were performed using R 4.4.2 (R Core Team, 2026).

Results

Young cucumber plants onto which predators were released on the same day as prey infestation at a 1:6.7 predator-prey ratio

The mean number of *T. putrescentiae* eggs per plant was significantly influenced by the presence of predator ($\chi 2$ = 104.21; df = 1; $P < 0.0001$), time ($\chi 2$ = 211.03; df = 4; $P < 0.0001$), and their interaction ($\chi 2$ = 98.21; df = 4; $P < 0.0001$). There was also a significant effect of predator presence ($\chi 2$ = 89.78; df = 1; $P < 0.0001$) and time ($\chi 2$ = 172.62; *df* = 6; $P < 0.0001$), as well as their interaction ($\chi 2$ = 118.07; df = 6; $P < 0.0001$) on the mean number of *T. putrescentiae* motiles per plant.

One, two, three, and four days after the release of *B. mali*, the mean numbers of *T. putrescentiae* eggs and motiles per cucumber plant in the treatment (T1) were significantly lower than those in the control (K1) ($P < 0.01$) (Figure 2a and 2b). The population of *T. putrescentiae* was very low two days after the predator's release. The mean number of *B. mali* (eggs and motiles) per cucumber plant also decreased with time after their release (Figure S1).

The proportion of *T. putrescentiae* (eggs and motiles) on the same leaves on which these were released decreased with time towards the end of the trial and was very low after the third day. On other leaves, it increased with time towards the end of the trial and was very high after the third day (Figure S2). The proportion of *B. mali* on the other leaves was significantly higher after two days than after one day (Figure S3).

The efficiency of *B. mali* increased over time, reaching the highest value of 95.50% after two days of predator release (Figure 3). In treatments (T1) and controls (K1), cumulative mite-days of *T. putrescentiae* per cucumber plant after one, two, three, four, and five days of the release of *B. mali* are presented in Table S1. The presence of *B. mali* in treatment T1 reduced the infestation of *T. putrescentiae* by 274.4 cumulative mite-days at the end of the trial, i.e., after five days of the release of *B. mali* (Table S1).

Young cucumber plants onto which predators were released after one day of prey infestation at a 1:33.3 predator-prey ratio

The effect of the presence of predator ($\chi2$ = 99.04; df = 1; $P < 0.0001$) on the mean number of *T. putrescentiae* eggs per plant was significant, while the effect of time ($\chi2$ = 160.32; df = 7; $P > 0.05$) and its interaction with treatment ($\chi2$ = 207.31; df = 7; $P > 0.05$) was nonsignificant. However, there was a significant effect of predator presence ($\chi2$ = 68.91; df = 1; $P < 0.0001$) and time ($\chi2$ = 110.62; df = 7; $P < 0.0001$) as well as their interaction ($\chi2$ = 192.22; df = 7; $P < 0.0001$) on the mean number of *T. putrescentiae* motiles per plant.

One, two, three, four, five, and six days after the release of *B. mali,* the mean numbers of *T. putrescentiae* eggs and motiles per cucumber plant were significantly lower in the treatment than those in the control (K2) ($P < 0.01$) (Figure 4a and 4b). By the fifth day following the release of the predator, the *T. putrescentiae* exhibited remarkably low population levels. The mean number of *B. mali* (eggs and motiles) per cucumber plant also decreased with time after their release (Figure S4).

The proportion of *T. putrescentiae* on the same leaves onto which these were released fluctuated with time and was the highest both at the beginning and end of the trial. Whereas the proportion of *T. putrescentiae* on the other leaves fluctuated with time and was the lowest both at the beginning and end of the trial (Figure S5). Some *B. mali* were found under platforms after 14 h (0.58 day) of their release, and after one day, they were observed on the other leaves (Figure S6). A larger proportion of *B. mali* was dispersed on the other leaves after two days, and then their proportion on the other leaves dropped and became very low in the following days (Figure S6).

The efficiency of *B. mali* increased over time, reaching a maximum of 99.48% after five days of predator release (Figure 5). In treatments (T2) and controls (K2), cumulative mite-days of *T. putrescentiae* per cucumber plant after one, two, three, four, five, six, and seven days of the release of *B. mali* are shown in Table S2. The presence of *B. mali* in treatment T2 reduced the infestation of *T. putrescentiae* by 2413.5 cumulative mite-days at the end of the trial, i.e., seven days after the release of *B. mali* (Table S2).

Discussion

The results of the present study demonstrated that *B. mali* effectively suppressed and minimized the *T. putrescentiae* population on young cucumber plants to significantly low levels within just two to five days. This was observed in two days on cucumber plants when the predators were introduced following the prey release on the same day at a predator-prey ratio of 1:6.7. Alternatively, when predators were released one day after initial infestation at a ratio of 1:33.3, a similar reduction in pest population was also achieved within five days. Across both tests, the mean numbers of *T. putrescentiae* eggs and motiles per plant were significantly lower in the treatment than those in the control each day after the release of *B. mali*. In both tests, both *B. mali* and *T. putrescentiae* dispersed after their release on the plant from the leaf on which they were placed to other leaves. When predators were released on the same day as the prey, at a ratio of 1:6.7, they achieved a 95.50% reduction in mite populations within just two days. Alternatively, releasing the predators one day after the initial infestation at a higher ratio of 1:33.3 resulted in a 99.48% decrease after five days. In terms of overall mite suppression measured by cumulative mite-days, there was a reduction of 274.44 mite-days over five days when predators were introduced immediately after prey release at 1:6.7. Conversely, when predators were released one day post-infestation at 1:33.3, the reduction was more substantial, totaling 2413.54 mite-days over seven days.

It is known that predator-prey dynamics are inherently unstable, often resulting in local extinction of one or both species after some time (Pels and Sabelis 1999; Mayland *et al.* 2000). However, in cucumber seedlings, the injury produced by *T. putrescentiae* before its local extinction may cause serious damage to leaves. Acarid mites are often dangerous for young cucumber plants with cotyledons and several true developing leaves, rather than older plants (Nakao 1991, Michalska K., personal observations). Larger infestations than tested in the present study were found when the cucumber seedlings were mulched using straw from which acarid mites migrated onto seedlings (K. Michalska, personal observation). Straw mulching is a common method of cultivation of some crop plants, including cucumber (Hnilička *et al.* 2012). However, decayed straw can be a habitat of *Tyrophagus* sp., which at higher densities can attack young leaves of greenhouse vegetables and ornamental plants (Zhang 2003). It should be emphasized that acarid mites, including *T. putrescentiae*, are not only commonly used in mass-rearing of predatory mites but are also considered as an alternative diet for the predators in crops. Pirayeshfar *et al*. (2021) showed that among several tested species of acarid mites, the application of *Thyreophagus entomophagus* (Laboulbene) as a living or frozen diet directly on chrysanthemum plants had a particularly positive impact on the population of the phytoseiid mite, *Amblyseius swirskii* (Athias-Henriot). However, the authors also admitted that live acarid mites can be harmful to young plants. This limits their use in crops, as also confirmed by the present study. This study suggests that to prevent potential damage, *B. mali* should be released as soon as the presence of *T. putrescentiae* is detected in the nursery of cucumber seedlings or other cucurbitaceous crops, or even pre-emptively, especially when straw mulching is applied. The necessity of biological control of *T. putrescentiae* on cucumber plants may be limited to a few weeks in the nursery, and one or two applications of *B. mali* at a weekly interval may be satisfactory. To confirm this, however, further investigations under more realistic crop conditions are needed.

Previous studies show that the ability of a predatory mite to suppress pests is strongly influenced by its capacity to disperse from the release site to other areas and seek prey throughout the crop (Skirvin and Fenlon 2003; Buitenhuis *et al.* 2010; Parolin *et al.* 2014). This study indicated that *B. mali* could disperse from the release sites on cucumber plants as early as one day after their release. It most probably followed *T. putrescentiae*, which also dispersed to other leaves on the plant within one day after *B. mali* release. These changes might be related to mite reproduction and *B. mali* predation. The effect of *T. putrescentiae's* population density on its antipredator behavior has not been tested yet. These acarid mites release both alarm and aggregation pheromones (Kuwahara 2004). It is likely that when *T. putrescentiae* population density was low, dispersion occurred, as observed in the test with a higher predator-prey ratio. But when the *T. putrescentiae* population was dense, the mite might be rather sedentary and, instead of escaping, it might more often form dense aggregations, in which "the illusion and confusion effects" worked better as defense. Under these circumstances, observed fluctuations in the proportion of *T. putrescentiae* on the same leaf could result more from *T. putrescentiae* reproduction and predation than from their "coming back" on the same leaf. However, to clarify these interesting issues, more studies on the anti-predatory behavior of *T. putrescentiae* and predator-prey dynamics are needed.

Similar to the present findings, *B. mali* revealed very high efficiencies in controlling *P. operculella* infestations on stored potato tubers and *T. putrescentiae* infestations on stored flower bulbs. Gallego *et al.* (2020) observed that *B. mali* achieved a maximum efficiency of 92.51% at the highest dose tested in controlling *P. operculella* infesting stored potato tubers under laboratory conditions and over a short term. Likewise, Solano-Rojas *et al.* (2022) reported that this mite species presented an efficiency of 94.85% in reducing the adult *P. operculella* population infesting stored potato tubers. Similarly, a more recent study by Jena *et al.* (2026) showed that the efficiencies of *B. mali* were 93.75%, 91.98%, 92.71% and 95.01% in controlling *T. putrescentiae* infesting lily bulbs stored without peat with a 1:40 predator-prey ratio, lily bulbs stored with peat with a 1:40 predator-prey ratio, stored tulip bulbs with a 1:40 predator-prey ratio, and stored tulip bulbs with a 1:20 predator-prey ratio, respectively.

Cumulative mite-days integrate both the magnitude of the number of mites and their duration over time into a single expression. This metric serves as an index of the overall effectiveness of the treatments (Ruppel 1983). Cumulative insect-days or mite-days have been used for biological control evaluation under field conditions (Sanchez and Lacasa 2008; Cabello *et al.* 2012) and storage conditions (Solano-Rojas *et al.* 2022; Jena *et al.* 2026) as well as in integrated pest management programs (Hoy 1985). A study performed by Jena *et al.* (2026) revealed that *B. mali* reduced the infestation of *T. putrescentiae* infesting flower bulbs by 32211.3, 39046.8, 34019.2, and 15238.5 cumulative mite-days in the following treatments: lily bulbs stored without peat with a 1:40 predator-prey ratio, lily bulbs stored with peat with a 1:40 predator-prey ratio, stored tulip bulbs with a 1:40 predator-prey ratio, and stored tulip bulbs with a 1:20 predator-prey ratio, after 25, 25, 25, and 15 days of predator release, respectively. The present study showed that the reduction in *T. putrescentiae* infestation was 274.44 cumulative mite-days five days after predator release when the predators were introduced following the prey release on the same day at a predator-prey ratio of 1:6.7 and 2413.54 cumulative mite-days seven days after predator release, when predators were released one day after initial infestation at a ratio of 1:33.3. The reduction in infestation, in terms of cumulative mite days, observed in the present study was much smaller than that reported by Jena *et al.* (2026), which might be due to differences in predator-prey ratios, food types, and environmental conditions.

In summary, the study indicated that the predatory soil mite *B. mali* had a great potential to reduce the population of *T. putrescentiae* infesting young cucumber plants when predators were released on plants following prey release on the same day as the prey infestation, at a 1:6.7 predator-prey ratio, and after one day of infestation at a 1:33.3 ratio. The predator *B. mali* may be used as a practical and sustainable alternative for managing acarid mite pests infesting young cucumber plants and other cucurbitaceous crops. However, additional studies under greenhouse and field conditions are necessary to confirm this. Further studies on the ability of *B. mali* to locate cucumber plants infested with *T. putrescentiae*, the role of odors emitted by the infested plant in finding the *T. putrescentiae,* and tritrophic interactions among plant, herbivore, and predator may increase the effectiveness of biological control of *T. putrescentiae* in the nursery of cucurbitaceous plants in different geographical regions.

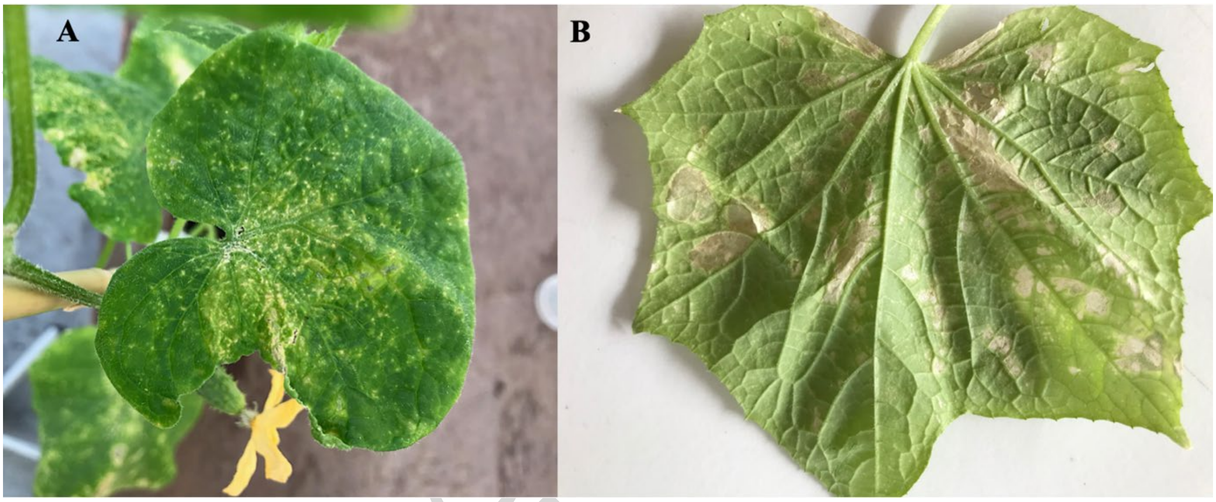

Figure 1. Symptoms of heavy infestation of young glasshouse cucumber plants cv. 'Skierniewicki' by Tyrophagus putrescentiae. A- Leaf discoloration and malformation after mite attack of seedlings at the stage of 1-2 true developing leaves; small feeding holes are present at the base of a young leaf. B - Numerous, large yellowish spots with severe tissue losses after infestation of unfolded, expanding leaves of young plants at the stage of 5-6 true leaves with approximately 600 T. putrescentiae motiles per leaf.

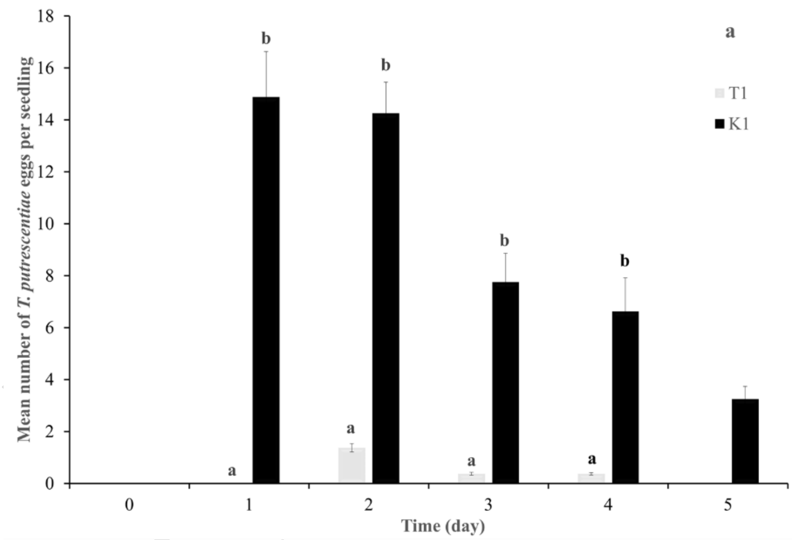

Figure 2A. The mean (±SE) numbers of Tyrophagus putrescentiae eggs (a) and motiles (b) per cucumber plant of the cultivar 'Skierniewicki' on respective days when Blattisocius mali was released on plants following T. putrescentiae release on the same day at a 1:6.7 predator-prey ratio (T1) compared to the control (K1) under semi-natural conditions. Day "0" means the day of the release of B. mali in the treatment (T1). Values with different letters indicate significant differences between treatment (T1) and control (K1) on the same day (Tukey test: $P < 0.05$).

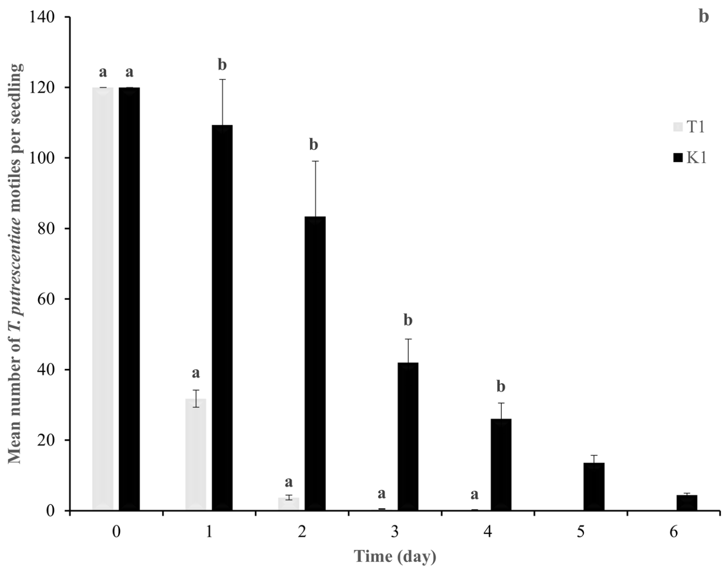

Figure 2B. The mean (±SE) numbers of Tyrophagus putrescentiae eggs (a) and motiles (b) per cucumber plant of the cultivar 'Skierniewicki' on respective days when Blattisocius mali was released on plants following T. putrescentiae release on the same day at a 1:6.7 predator-prey ratio (T1) compared to the control (K1) under semi-natural conditions. Day "0" means the day of the release of B. mali in the treatment (T1). Values with different letters indicate significant differences between treatment (T1) and control (K1) on the same day (Tukey test: $P < 0.05$).

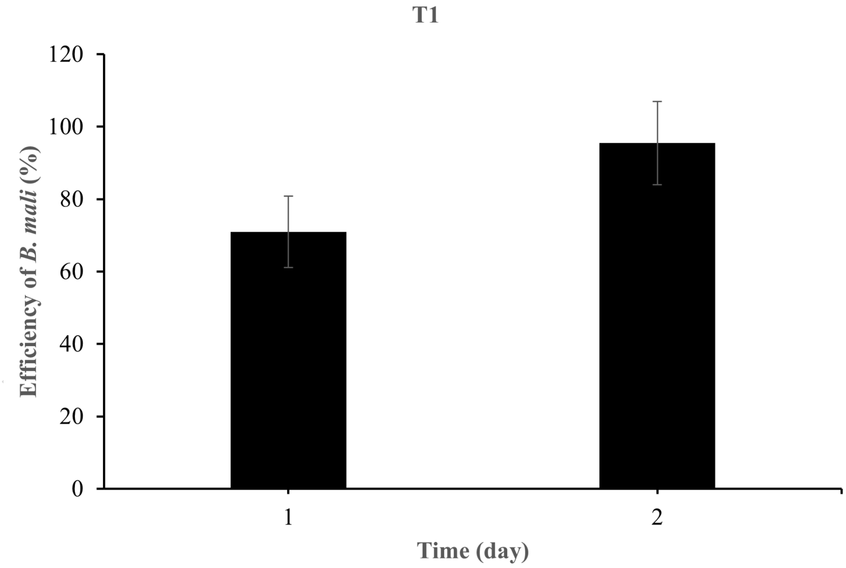

Figure 3. The efficiency (±SE) of Blattisocius mali, determined using a Generalized Linear Mixed Model suggested by Piepho *et al*. (2024), in controlling Tyrophagus putrescentiae on respective days when B. mali was released on young cucumber plants of the cultivar ‘Skierniewicki’ following T. putrescentiae release on the same day at a 1:6.7 (T1) predator-prey ratio under semi-natural conditions.

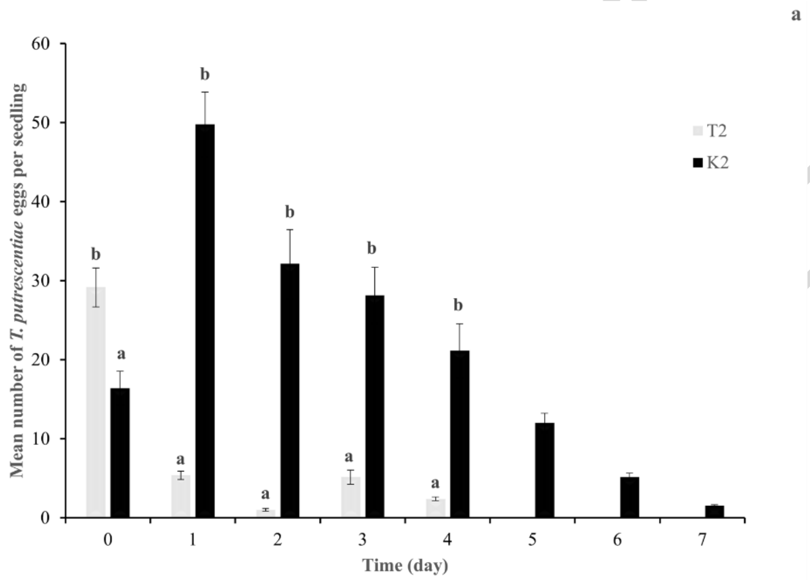

Figure 4A. The mean (±SE) numbers of Tyrophagus putrescentiae eggs (a) and motiles (b) per cucumber plant of the cultivar ‘Skierniewicki’ on respective days when Blattisocius mali was released on plants after one day of T. putrescentiae release at a 1:33.3 (T2) predator-prey ratio compared to the control (K2) under semi-natural conditions. Day “0” means the day of the release of B. mali in the treatment (T2). Values with different letters indicate significant differences between treatment (T2) and control (K2) on the same day (Tukey test: P < 0.05).

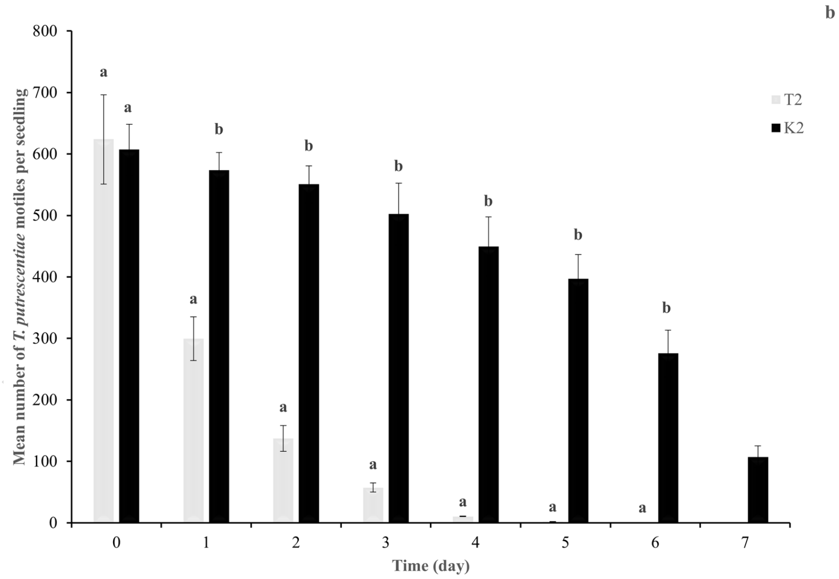

Figure 4B. The mean (±SE) numbers of Tyrophagus putrescentiae eggs (a) and motiles (b) per cucumber plant of the cultivar ‘Skierniewicki’ on respective days when Blattisocius mali was released on plants after one day of T. putrescentiae release at a 1:33.3 (T2) predator-prey ratio compared to the control (K2) under semi-natural conditions. Day “0” means the day of the release of B. mali in the treatment (T2). Values with different letters indicate significant differences between treatment (T2) and control (K2) on the same day (Tukey test: $P < 0.05$).

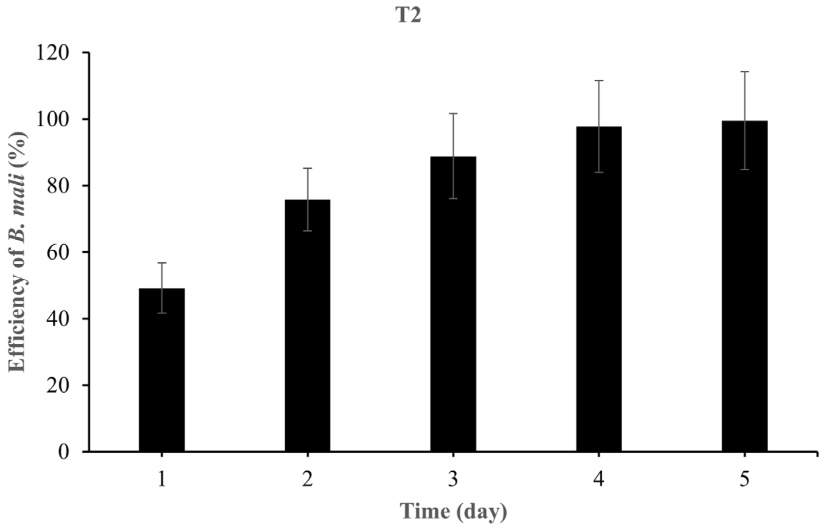

Figure 5. The efficiency (±SE) of Blattisocius mali, determined using a Generalized Linear Mixed Model suggested by Piepho *et al.* (2024), in controlling Tyrophagus putrescentiae on respective days when B. mali was released on cucumber plants of the cultivar ‘Skierniewicki’ after one day of T. putrescentiae release at a 1:33.3 (T2) predator-prey ratio under semi-natural conditions.

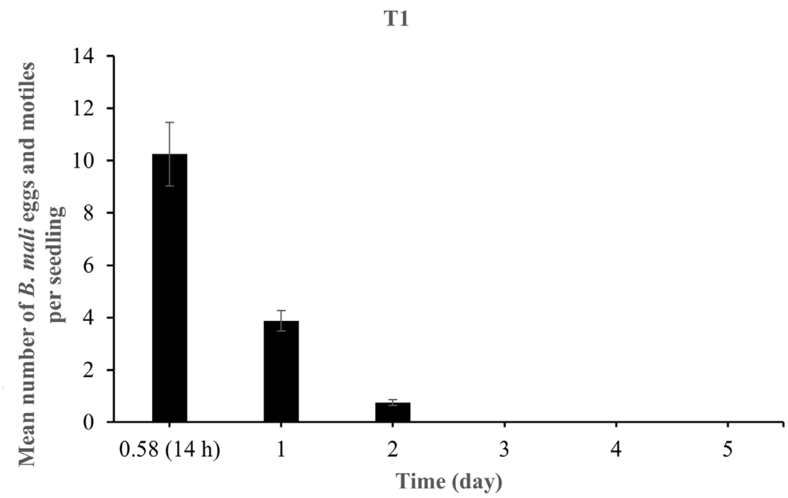

Figure S1. The mean (±SE) numbers of Blattisocius mali (eggs and motiles) per cucumber plant of the cultivar 'Skierniewicki' on respective days when B. mali was released on plants following Tyrophagus putrescentiae release on the same day at a 1:6.7 (T1) predator-prey ratio under semi-natural conditions.

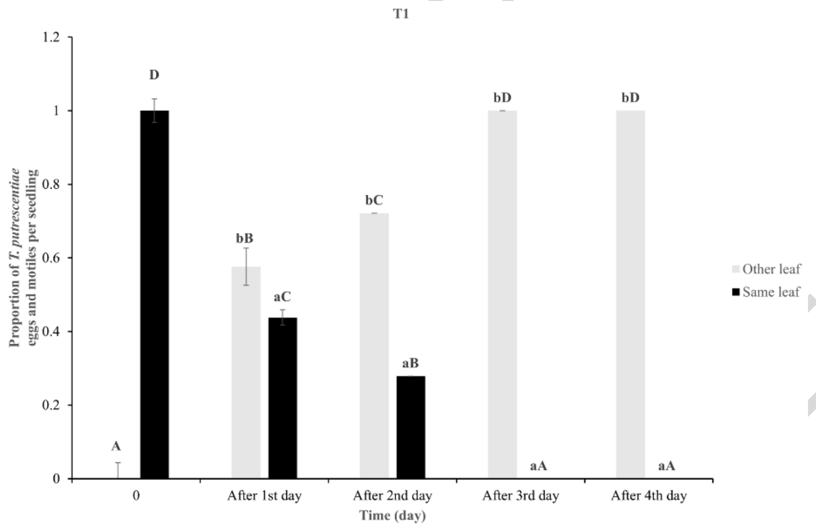

Figure S2. The proportion (±SE) of Tyrophagus putrescentiae (eggs and motiles) on the same leaf and other leaves per cucumber plant of the cultivar 'Skierniewicki' on respective days when Blattisocius mali was released on plants following T. putrescentiae release on the same day at a 1:6.7 (T1) predator-prey ratio under semi-natural conditions. Uppercase and lowercase letters indicate significant differences between days within a leaf type and leaves in a day, respectively, based on the "Tukey test" ($P < 0.05$).

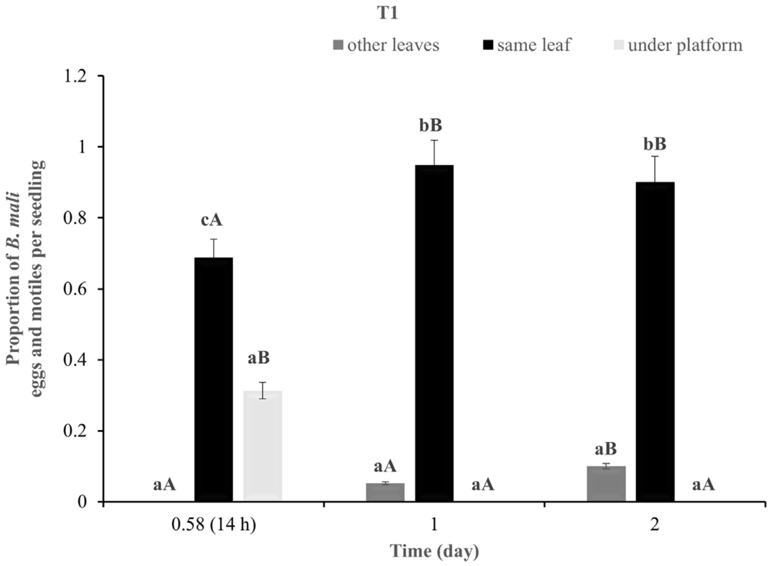

Figure S3. The proportion (±SE) of Blattisocius mali (eggs and motiles) on the same leaf, other leaves, and under the platform per cucumber plant of the cultivar 'Skierniewicki' on respective days when B. mali was released on plants following Tyrophagus putrescentiae release on the same day at a 1:6.7 (T1) predator-prey ratio under semi-natural conditions. Uppercase and lowercase letters indicate significant differences between days at a location and locations in a day, respectively, based on the "Tukey test" (P < 0.05).

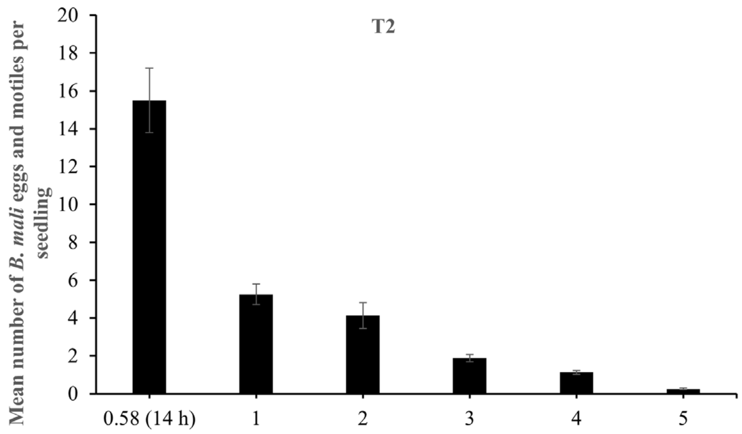

Figure S4. The mean (±SE) numbers of Blattisocius mali (eggs and motiles) per cucumber plant of the cultivar 'Skierniewicki' on respective days when Blattisocius mali was released on plants after one day of T. putrescentiae release at a 1:33.3 (T2) predator-prey ratio under semi-natural conditions.

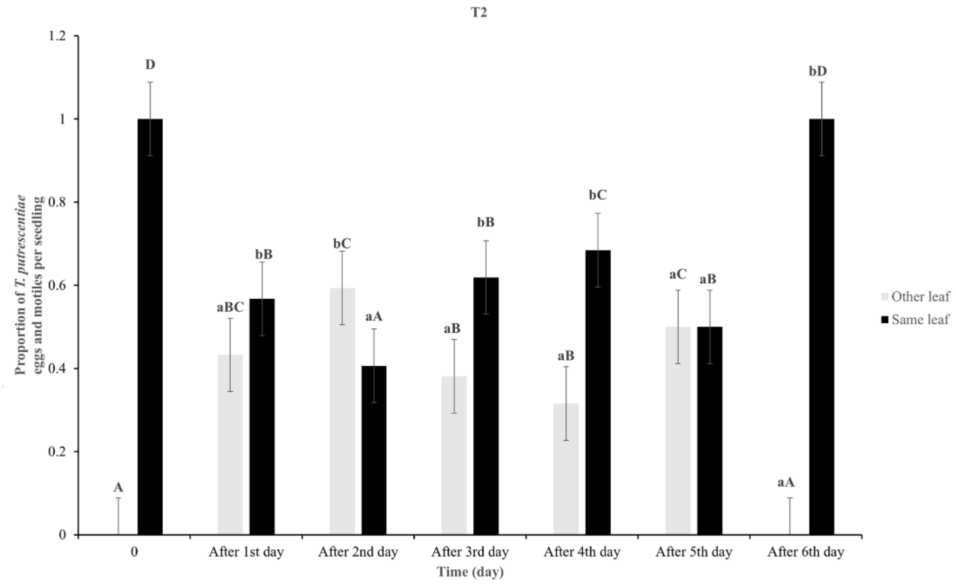

Figure S5. The proportion (±SE) of Tyrophagus putrescentiae (eggs and motiles) on the same leaf and other leaves per cucumber plant of the cultivar 'Skierniewicki' on respective days when Blattisocius mali was released on plants after one day of T. putrescentiae release at a 1:33.3 (T2) predator-prey ratio under semi-natural conditions. Uppercase and lowercase letters indicate significant differences between days within a leaf type and leaves in a day, respectively, based on the "Tukey test" (P < 0.05).

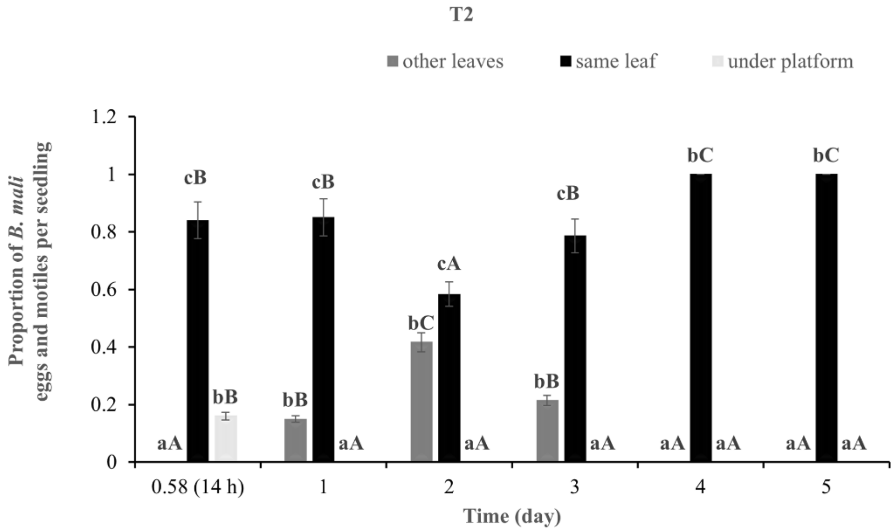

Figure S6. The proportion (±SE) of Blattisocius mali (eggs and motiles) on the same leaf, other leaves, and under the platform per cucumber plant of the cultivar 'Skierniewicki' on respective days when B. mali was released on plants after one day of T. putrescentiae release at a 1:33.3 (T2) predator-prey ratio under semi-natural conditions. Uppercase and lowercase letters indicate significant differences between days at a location and locations in a day, respectively, based on the "Tukey test" (P < 0.05).

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Supplementary Tables

Table S1. Cumulative mite-days of *Tyrophagus putrescentiae* on respective days when *B. mali* was released on young cucumber plants of the cultivar 'Skierniewicki' following *T. putrescentiae* release on the same day at a 1:6.7 predator-prey ratio (T1) compared to the control (K1) under semi-natural conditions.

Time (day)	Cumulative mite-days (day)		Reduction in cumulative mite-days over control (day)
	K1	T1	K1−T1
1	122.1	75.8	46.2
2	233.1	94.3	138.8
3	306.8	97.3	209.4
4	348.0	98.1	249.9
5	372.8	98.4	274.4

Table S2. Cumulative mite-days of *Tyrophagus putrescentiae* on respective days when *B. mali* was released on young cucumber plants of the cultivar 'Skierniewicki' after one day of *T. putrescentiae* release at a 1:33.3 predator-prey ratio (T2), compared to the control (K2) under semi-natural conditions.

Time (day)	Cumulative mite-days (day)		Reduction in cumulative mite-days over control (day)
	K2	T2	K2−T2
1	622.8	478.8	144.1
2	1225.6	700.3	525.2
3	1781.8	800.8	981.1
4	2282.1	838.6	1443.4
5	2721.6	846.1	1875.5
6	3066.4	847.5	2218.9
7	3261.4	847.8	2413.5