

1 **Impact of temperature shifts on prey consumption and prey**
2 **preference of the predatory mite *Amblyseius andersoni* (Acari:**
3 **Phytoseiidae)**

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5 **Chenhao Wang^{1*}, Minori Sekiguchi², Norihide Hinomoto¹**

6 ¹ Laboratory of Ecological Information, Graduate School of Agriculture, Kyoto University,
7 Sakyo-ku, Kyoto, 606-8502, Japan

8 ² Arysta LifeScience Corporation, Nihonbashi 1-chome Mitsui Building, 1-4-1, Nihonbashi,
9 Chuo-ku, Tokyo, 103-0027, Japan

10 *Correspondence: wang.chenhao.b93@kyoto-u.jp

11 +81-75-753-6135

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13 Running title: Prey preference of *Amblyseius andersoni*

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Abstract

In practical agricultural systems, multiple pest species often coexist, posing a significant challenge for pest control. Polyphagous predatory mites, especially Phytoseiidae, play a dominant role in biological control, owing to their ability to suppress multiple pests. Currently, there is a lack of information on the effect of temperature shifts on prey preference of polyphagous predatory mites. In this study, we examined the prey consumption and prey preference of *Amblyseius andersoni* (Chant) on two important agricultural pests, the two-spotted spider mite (*Tetranychus urticae* Koch) and the western flower thrips (*Frankliniella occidentalis* Pergande), at five different temperatures (15, 20, 25, 30, and 35°C). The preference for *T. urticae* larvae weakened with increasing temperature; the maximum at 15°C (Manly's preference index $\beta = 0.8952$) and the minimum at 30°C ($\beta = 0.6584$). The prey consumption of *T. urticae* was the lowest at 35°C (5.93 per day) and the highest at 25°C (9.23 per day); the highest and the lowest prey consumption of *F. occidentalis* were observed at 30°C (1.73 per day) and 15°C (0.33 per day), respectively. Moreover, we found that the prey preference of *A. andersoni* on the two prey may be related to the antipredator behavior of *F. occidentalis*, but not to the relative ratios of prey. Our study highlights the importance of temperature conditions when using generalist natural enemies to control multiple pests.

Keywords

Biological control; *Frankliniella occidentalis*; Phytoseiidae; polyphagous predator; *Tetranychus urticae*

Introduction

With the excessive use of chemical pesticides, traditional chemical control methods have become ineffective in managing specific pests, such as the two-spotted spider mite (*Tetranychus urticae* Koch (Acari: Tetranychidae)) and the western flower thrips (*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)), owing to the rapid development of resistance (Gao *et al.*, 2012; Van Leeuwen *et al.*, 2010; Hada *et al.*, 2016; Zhang *et al.*, 2022; Han & Rotenberg, 2024; Ye *et al.*, 2024). Due to their short lifespans, high reproductive rates, and arrhenotokous reproduction, these two species exhibit remarkable adaptability to various compounds and rapidly develop resistance (Danks, 2006; Xu & Enkegaard, 2010; Mouden *et al.*, 2017). Owing to these biological characteristics, these species are extremely destructive for ornamentals and vegetables all over the world and lead to significant yield reductions and economic losses in crops (Hussey & Parr, 1963; Reitz, 2009; Tuan *et al.*, 2016; Mouden *et al.*, 2017; Schneweis *et al.*, 2017; He *et al.*, 2020; Jyothis & Ramani, 2024). Excessive pesticide use may significantly harm human health and global ecosystems (Huang *et al.*, 2022). Therefore, environment-friendly pest control methods are required for the long-term sustainability of agricultural systems. Against this backdrop, biological control via the release of natural enemies has increasingly gained attention as an effective pest management approach, contributing to sustainable development by reducing reliance on chemical pesticides (van Lenteren, 2012; Shimoda *et al.*, 2015; van Lenteren *et al.*, 2018).

Polyphagous predatory mites, mostly from the family Phytoseiidae, are the dominant biological control agents in many countries, owing to their ability to control a variety of pests.

Moreover, they can survive on crops before pest outbreaks by feeding on food provided by plants, such as pollen and nectar (McMurtry & Croft, 1997; van Lenteren *et al.*, 2018). *Amblyseius andersoni* (Acari: Phytoseiidae) is a dominant species in the orchards of North America, Europe, and the Arabian region, serving as an effective biological control agent (Barbar, 2014; Tixier *et al.*, 2014). It was recently reported in Japanese apple orchards (Toyoshima *et al.*, 2016). *Amblyseius andersoni* is a polyphagous predator, classified as a Type III generalist, which feeds on various mites, thrips, and pollen (McMurtry *et al.*, 2013; Funayama, 2024). Howell and Daugovish (2016) showed that releasing *A. andersoni* in greenhouses effectively reduced the *T. urticae* populations. Sengonca *et al.* (2004) also showed that *A. andersoni* can prey on *F. occidentalis* larvae in greenhouses. In practical agricultural systems, it is common for multiple pest species to coexist simultaneously. For example, *T. urticae* and *F. occidentalis* frequently co-exist in certain vegetables, such as beans and cucumbers (Pallini *et al.*, 1998; Mérida-Torres *et al.*, 2024). The preference of *A. andersoni* for both pests has not been explicitly indicated in the literature, nor has its efficiency in simultaneously controlling them been confirmed.

Predatory mites are ectothermic animals whose physiological functions, life cycles, and behaviors are directly influenced by temperature (Skirvin & Fenlon, 2003; Gotoh *et al.*, 2004; Lee & Gillespie, 2010; Li *et al.*, 2019; Farazmand *et al.*, 2020; Farazmand & Amir-Maafi, 2021). For example, temperature affects the developmental rate and body size of *Phytoseiulus persimilis* (Tscholl *et al.*, 2022), and high temperatures can accelerate the rate of *A. andersoni* development and increase their fecundity (Li *et al.*, 2019). Most laboratory predation experiments are conducted in an ideal environment, typically around 25°C, which is a suitable

temperature for predatory mites (Blackwood *et al.*, 2001; Xiao & Fadamiro, 2010; Xu & Enkegaard, 2010; Patel & Zhang, 2017). However, in practice, the temperature in fields or greenhouses may not always be optimal for predatory mites. Therefore, transferring *A. andersoni*, reared at optimal temperature, to environments with different temperatures for pest control may affect their control efficacy. Metabolism in animals increases with increasing temperatures, leading to a greater requirement for food (Lima & Dill, 1990). Elevated temperatures increase animal activity, leading to higher encounter rates between predators and prey, which subsequently results in an indirect rise in predation rates (Frances & McCauley, 2018). It remains unclear whether the predation on the two pests by *A. andersoni* increases at higher temperatures, and whether its prey preference shifts in response to temperature changes. Clarifying these interactions is essential for evaluating the potential of *A. andersoni* to effectively suppress both pest species simultaneously.

In this study we investigated the prey preference and prey consumption of *A. andersoni* for *T. urticae* and *F. occidentalis*. We further examined whether the prey preference was influenced by the antipredator behavior of *F. occidentalis* and different relative ratios of prey. Attention was also focused to explore the effects of temperature on the prey preference and prey consumption of *A. andersoni*. The aim of this study was to evaluate the potential of using the polyphagous predatory mite *A. andersoni* for controlling both the pests at different temperatures.

Materials and methods

102 *Mites*

103 The *T. urticae* population was initially collected in 1998 from chrysanthemum plants
104 (*Chrysanthemum morifolium* Ramat.) in Nara, Japan. It was subsequently reared on the
105 primary leaves of kidney beans (*Phaseolus vulgaris* L.), with the adaxial side placed upward
106 on water-saturated cotton in Petri dishes (9.0 cm in diameter, 1.4 cm in height). The water-
107 saturated cotton served as a barrier to prevent the mites from escaping. The Petri dishes were
108 maintained at 25°C, under 50% relative humidity and a 16L:8D photoperiod. All experiments
109 were conducted under these conditions, except for the one to assess the effect of temperature
110 on prey preference and prey consumption.

111 The *A. andersoni* population obtained Arystra LifeSciences Co. Ltd (Tokyo, Japan) was
112 reared in a plastic box (10.0 × 10.0 × 6.5 cm) that contained bran up to two-thirds its height.
113 The plastic box was placed into a larger plastic tray (22.0 × 15.0 × 9.0 cm), filled with
114 approximately 2 cm of water containing a drop of dishwashing detergent to prevent them
115 from escaping. Every third day, the predatory mites were supplied with 0.6 g of sugar, which
116 was distributed across the surface of the bran, to feed the dried fruit mite *Carpoglyphus lactis*
117 (L.) (Carpoglyphidae) as prey.

118 *Thrips*

119 The *F. occidentalis* population was collected from chrysanthemums in 2017 in Osaka, Japan,
120 and reared on germinating broad beans (*Vicia faba*). Using a small knife, the growing tips of
121 the sprouts were carefully trimmed. The beans were placed in a tight box (12.5 × 9.0 × 4.0 cm)
122 with a mesh-covered ventilation opening (Ø 1.5 cm) in the tight-fitting lid. Every third day the

thrips were provided with fresh beans.

Experimental setup

For all experiments, bean leaf squares (2.0×2.0 cm) were used as experimental arenas (Fig. 1). Each leaf square was placed upside down on the top of a cotton square (2.2×2.2 cm) in a petri dish ($\varnothing$ 5.0 cm) with a mesh-covered ventilation opening ($\varnothing$ 1.5 cm) in the cover. Water was added to the Petri dish until it covered the cotton, creating a barrier for the mites and thrips to prevent them from escaping the leaf.

Prey-stage preference and prey preference

The prey-stage preference of *A. andersoni* was determined by using different stages of the two prey, *T. urticae* (eggs, larvae) and *F. occidentalis* (first-instar larvae). In our preliminary experiments, *Amblyseius andersoni* rarely preyed on the second-instar larvae of *F. occidentalis*. Each female *A. andersoni* was singly transferred to the arena, which included 20 *T. urticae* eggs and 20 larvae, and allowed to prey for 24 hours. A total of 30 replicates of the experiment were performed. Thereafter, the preference of *A. andersoni* was determined using the most preferred stages of the two pests. Based on the results, *T. urticae* larvae and *F. occidentalis* first-instar larvae were selected for further experiments. Each female *A. andersoni* was singly transferred to the arena, which included 15 *T. urticae* larvae and 5 *F. occidentalis* first-instar larvae, and was allowed to prey for 24 h. The ratio of *T. urticae* to *F. occidentalis* was set based on the predator's similar consumption capacity for both prey species within 24 hours, as determined by preliminary experiments. A total of 30 replicates of the experiment were performed; each leaf square, each predator female, and each prey was

144 used only once.

145 *Effect of antipredator behavior*

146 Some *F. occidentalis* first-instar larvae were placed in a freezer (-18°C) for 24 h to eliminate
147 the antipredator behavior of *F. occidentalis*. A single female *A. andersoni* was initially
148 transferred to the arena with five frozen and five non-frozen *F. occidentalis* first-instar larvae
149 to evaluate its willingness to feed on freeze-killed *F. occidentalis* first-instar larvae by
150 comparing the consumption of the two types of larvae. Thereafter, 5 frozen *F. occidentalis*
151 first-instar larvae and 15 *T. urticae* larvae were transferred to one arena. A single female *A.*
152 *andersoni* was then transferred to the arena and was allowed to prey for 24 hours. A total of
153 20 replicate experiments were performed.

154 *Effect of providing prey at different ratios*

155 A starting ratio of 15 *T. urticae* larvae to 5 *F. occidentalis* first-instar larvae was set at 1:1.
156 Based on this, four additional ratios were established: 1:2 (15 *T. urticae* larvae to 10 *F.*
157 *occidentalis* first-instar larvae), 2:1 (30 *T. urticae* larvae to 5 *F. occidentalis* first-instar
158 larvae), 1:0 (15 *T. urticae* larvae and no *F. occidentalis* first-instar larvae), 0:1 (no *T. urticae*
159 larvae but only 5 *F. occidentalis* first-instar larvae). The preference of *Amblyseius andersoni*
160 for the two prey species was evaluated at three ratios: 1:2 (15:10), 1:1 (15:5), and 2:1 (30:5),
161 and the consumption of both pests by *A. andersoni* was assessed at five ratios: 0:1 (0:5), 1:0
162 (15:0), 1:2 (15:10), 1:1 (15:5), and 2:1 (30:5). Each ratio combination was replicated 30
163 times.

164 *Effect of exposure to different temperatures*

The prey preference of *A. andersoni* was evaluated at five temperatures: 15, 20, 25, 30, and 35°C. The experiments were conducted in an incubator (LH-55-RD, NKsystem, Osaka, Japan). Each female *A. andersoni* was singly transferred to the arena, which included 15 *T. urticae* larvae and 5 *F. occidentalis* first-instar larvae. A total of 30 replicate experiments were performed for each temperature.

Statistical analysis

The assessment of preference was based on the formula for the Manly's preference index (Manly, 1974; Chesson, 1978):

$$\beta_1 = \frac{\text{Log}\left(\frac{e_1}{A_1}\right)}{\text{Log}\left(\frac{e_1}{A_1}\right) + \text{Log}\left(\frac{e_2}{A_2}\right)}$$

where β_1 is the preference for prey species 1, e_1 and e_2 are, respectively, the number of prey type 1 and type 2 remaining after the experiment (in our research e_1 was *T. urticae* eggs and e_2 was *T. urticae* larvae or e_1 was *T. urticae* larvae and e_2 was *F. occidentalis* first-instar larvae), A_1 and A_2 are the numbers of each prey type provided. A preference index close to 1 suggests the preference for prey type 1, whereas a preference index close to 0 indicates the preference for prey type 2. An index close to 0.5 indicates no preference, implying random predation (Sherratt & Harvey, 1993).

Consumption counts and preference indexes were tested for normality using the Shapiro–Wilk test as well as for homoscedasticity using Levene's test. The Wilcoxon signed-rank test was used to compare the differences in the consumption of different prey. The Mann–Whitney *U* test or unpaired *t*-test was used to compare the differences in the consumption of the same prey under different treatments. The Kruskal–Wallis tests with pairwise comparisons or one-

way analysis (ANOVA) and Tukey's multiple comparisons test (HSD) were performed to examine the effects of prey ratios and temperatures on the prey preference and prey consumption. In all the tests, $P < 0.05$ was considered to indicate a significant difference. All analyses were performed using the Prism v.10.3.1 software (GraphPad Software, Boston, MA, USA).

Results

Prey-stage preference and prey preference

Amblyseius andersoni preyed significantly more proficiently on *T. urticae* larvae than on eggs (Fig. 2A, Wilcoxon signed-rank test, $P = 0.0121$) and had significant preferences for larvae (Fig. 3, $\beta_1 < 0.5$, 95% confidence intervals did not include $\beta = 0.5$). In the prey preference experiment, the consumption of *T. urticae* larvae and *F. occidentalis* first-instar larvae by *A. andersoni* was 9.23 and 1.17, respectively (Fig. 2B). The value (β_2) for *A. andersoni* was 0.78, which was greater than 0.5, suggesting that *A. andersoni* preferred to prey on *T. urticae* larvae (Fig. 3).

Eliminating the antipredator behavior

Amblyseius andersoni actively preyed on frozen *F. occidentalis* first-instar larvae, with the consumption being significantly higher than that of non-frozen *F. occidentalis* (Fig. 4, Wilcoxon signed-rank test, $P < 0.0001$). *Amblyseius andersoni* exhibited no preference between *T. urticae* larvae and frozen *F. occidentalis* first-instar larvae (Fig. 3, β_3 , 95% confidence intervals overlapped with $\beta = 0.5$). The consumption of frozen *F. occidentalis*

first-instar larvae by *A. andersoni* was significantly higher than that of non-frozen *F. occidentalis* between the two groups (Fig. 5, Mann–Whitney *U* test, $P < 0.0001$). On the contrary, the consumption of *T. urticae* larvae by *A. andersoni* showed no significant change, regardless of the presence of frozen or non-frozen *F. occidentalis* first-instar larvae (Fig. 5, unpaired *t*-test, $P = 0.0534$).

Effect of providing prey at different ratios

The β values at different relative ratios of prey showed no significant difference, indicating the absence of switching behavior in *A. andersoni* (Fig. 6, Kruskal–Wallis test, $H = 3.389$, $df = 2$, $P = 0.1837$). The consumption of *T. urticae* larvae by *A. andersoni* showed no significant difference at relative ratios of 1:0 (15:0), 1:2 (15:10), and 1:1 (15:5), but was significantly higher at the 2:1 (30:5) ratio compared with that at the other three ratios (Fig. 7, ANOVA, $F = 13.13$, $df = 3$, $P < 0.0001$). In contrast, the consumption of *F. occidentalis* first-instar larvae at relative ratios of 1:1 (15:5) and 2:1 (30:5) was significantly lower than that at the relative ratios of 1:2 (15:10) and 0:1 (0:5) (Fig. 7, Kruskal–Wallis test, $H = 55.25$, $df = 3$, $P < 0.0001$).

Effect of exposure to different temperatures

Although *A. andersoni* preferred to prey on *T. urticae* larvae at all temperatures, the preference for *T. urticae* larvae weakened at higher temperatures, especially at 30°C (Fig. 8, Kruskal–Wallis test, $H = 25.29$, $df = 4$, $P < 0.0001$). The consumption of *T. urticae* larvae by *A. andersoni* at 25°C and 30°C was significantly higher than that at 15°C, but the consumption was significantly lower at 35°C (Fig. 9, ANOVA, $F = 10.13$, $df = 4$, $P < 0.0001$). Similarly, except for 35°C, higher temperatures lead to increased consumption on *F.*

occidentalis first-instar larvae, which peaked at 30°C (Fig. 9, Kruskal–Wallis test, $H = 37.76$, $df = 4$, $P < 0.0001$). At 35°C, consumption of *F. occidentalis* first-instar larvae did not exhibit a significant decrease; and the consumption was not significantly different compared with that at 20°C, 25°C and 30°C.

Discussion

In this study, we aimed at investigating the prey preference of *A. andersoni* for *T. urticae* and *F. occidentalis*, as well as the effects of temperature on the prey preference and consumption of the two pests. *Amblyseius andersoni* was found to prefer *T. urticae* larvae to eggs (Fig. 3), which is consistent with the results reported in a previous study (Blackwood *et al.*, 2001). This may be related to the mouthparts of generalist species that are less effective at piercing the *T. urticae* egg chorion compared with those of specialized species, making the nutritional value of larvae and handling time incurred on consuming them more profitable than feeding on eggs for generalist species (Blackwood *et al.*, 2001; Xiao & Fadamiro, 2010). *Amblyseius andersoni* showed a preference for preying on *T. urticae* larvae over *F. occidentalis* first-instar larvae (Fig. 3). This preference might be attributed to the smaller size of *T. urticae* larvae, which makes them easier for predators to capture. Smaller prey require shorter handling times and are thus less energetically costly to capture and consume (Brose *et al.*, 2008; Portalier *et al.*, 2019; Meehan *et al.*, 2022). Moreover, *F. occidentalis* larvae use several defense mechanisms against their predators, such as abdominal swings and anal droplets, which make their being caught more difficult than the catching of *T. urticae* larvae (de Bruijn *et al.*, 2006;

Beretta *et al.*, 2024). To eliminate the effect of defense mechanisms, we conducted experiments using frozen *F. occidentalis* first-instar larvae and found that the consumption of frozen larvae by *A. andersoni* was higher than that of non-frozen larvae (Fig. 4). *Amblyseius andersoni* equally preferred to prey on frozen *F. occidentalis* first-instar larvae and *T. urticae* larvae (Fig. 5). Because *A. andersoni* had no prior exposure to either *T. urticae* or *F. occidentalis* during rearing, the prey preference was not affected by any early-life experience (Rahmani *et al.*, 2009; Schausberger & Peneder, 2017; Sarkar *et al.*, 2024). Consequently, *A. andersoni* may exhibit a preference for preying on *T. urticae* larvae, as capturing *F. occidentalis* first-instar larvae involves greater difficulty and higher energy expenditure.

Our results on the consumption under different ratios of prey showed that the presence of *T. urticae* significantly reduced the consumption of *F. occidentalis* by *A. andersoni* compared with the consumption when only *F. occidentalis* was provided (Fig. 7). In contrast, the number of consumed *T. urticae* did not change significantly regardless of the presence of *F. occidentalis*. This indicates that in the presence of *T. urticae*, using *A. andersoni* alone for controlling *F. occidentalis* is not particularly effective, as these mites do not actively target *F. occidentalis*. Thus, when employing *A. andersoni* for the control of *F. occidentalis* in the presence of large *T. urticae* populations, it is advisable to integrate other natural enemies for effective management of *F. occidentalis*. *Amblyseius andersoni* may be unsuitable for managing large-scale outbreaks of *F. occidentalis*. On the contrary, because *A. andersoni* can feed on food provided by plants, such as pollen and nectar (McMurtry *et al.*, 2013; Funayama, 2024;), they may be introduced to crops before the appearance of *F. occidentalis*, to help prevent *F. occidentalis* outbreaks.

High temperatures and extreme weather events are expected to become more frequent in the future (Ummenhofer & Meehl, 2017). In agricultural systems, high temperatures may increase the crop losses caused by pests (Deutsch *et al.*, 2018). *Tetranychus urticae* is more likely to benefit from high-temperature environments because they experience less negative impact from heat compared to their predators (Tscholl *et al.*, 2022; Walzer *et al.*, 2022; Tscholl *et al.*, 2023). *Frankliniella occidentalis* also exhibits high thermal tolerance, and its pupae and pre-pupae can mitigate the negative effects of high temperatures by regulating their metabolism (Wang *et al.*, 2014). Therefore, in the context of global warming, *T. urticae* and *F. occidentalis* may become even more widespread and problematic. On the contrary, some studies have indicated that high temperatures are unfavorable for natural enemies—high temperatures accelerated the development of both *T. urticae* and *P. persimilis*, especially speeding up the development of *T. urticae* and thereby greatly shortening their vulnerable larval stage (Walzer *et al.*, 2020; Walzer *et al.*, 2022). The body size of female *T. urticae* did not change significantly under high temperatures, whereas *P. persimilis* tended to become smaller (Tscholl *et al.*, 2022). *Phytoseiulus persimilis* exhibited higher escape and mortality rates under heat conditions (Tscholl *et al.*, 2023). Urbaneja-Bernat and Jaques (2022) suggested that in an increasingly hotter and drier Mediterranean region, three phytoseiid mite species, *Euseius stipulatus*, *Neoseiulus californicus*, and *P. persimilis*, will become less effective in controlling *T. urticae*. Prey consumption below 30°C was observed to vary in a manner consistent with the hypothesis, indicating that higher temperatures are associated with increased predation. In particular, predation on *T. urticae* was significantly higher at 25°C and 30°C than at 15°C. Similarly, predation on *F. occidentalis* was significantly higher at 25°C

and 30°C than at 15°C, and significantly higher at 30°C than at 20°C. (Fig. 9). Conversely, once the temperature reached 35°C, the consumption of *T. urticae* by *A. andersoni* declined. In other words, elevated temperatures within a certain range enhanced the predation rate of *A. andersoni*, consistent with the results observed in many other arthropods (Pakyari & Enkegaard, 2012; Walker *et al.*, 2020; Ramachandran *et al.*, 2021). Moreover, we document that temperature significantly influences the prey preference of predators. Although *A. andersoni* preferred to prey on *T. urticae* larvae at all temperatures, the preference for *T. urticae* larvae was lower, with significantly reduced preference at 30 °C and 35 °C compared with that at 15 °C (Fig. 8). This change is associated with a significant increase in predation on *F. occidentalis* at 30 °C and 35 °C, compared with that at 15 °C, and a significant decrease in predation on *T. urticae* at 35 °C. A possible explanation for this is that high temperatures may increase the mobility of both predators and prey (Lima & Dill, 1990; Kruse *et al.*, 2008), with *F. occidentalis* tending to move faster than *T. urticae* (Saito 1977; Thoen *et al.*, 2016), thereby significantly increasing the encounter rate between faster prey and predators.

In conclusion, our study demonstrates that the defense mechanisms of *F. occidentalis* influence the prey preference of *A. andersoni* and that temperature also affects both the prey preference and the prey consumption of *A. andersoni*. However, our experiments were conducted under controlled laboratory conditions, which may not fully capture the complexity of field environments, where multiple biotic and abiotic factors could influence predator-prey interactions. Moreover, the observations in this study were limited to a one-day experiment, and thus the long-term effects of temperature changes on predator efficacy and prey population dynamics were not assessed. Therefore, further research is needed to evaluate the

315 practical potential of *A. andersoni* as a biological control agent for managing multiple pests
316 under field conditions. Our study suggests that, in the context of global warming, the impact
317 of temperature on both natural enemies and pests deserves more attention. These changes in
318 behavior or reproduction can directly affect the efficacy of biological control by natural
319 enemies, thereby determining the success of the use of natural enemies for pest control.

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526

527 **Statements and Declarations**

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530 School of Agriculture at Kyoto University and Arystra LifeSciences Co. Ltd

531

532 **Author contributions**

533 CW, MS, and NH conceived the study idea, developed the experimental design. MS, and NH
534 acquired funding, provided resources. CW conducted the study, analyzed the data and wrote
535 the first draft of the manuscript. NH reviewed and edited the writing. CW, MS, and NH
536 contributed to the revision and approved the submission of the manuscript.

537

538 **Disclosure**

539 The authors declare no conflict of interest.

Figures legends

Fig. 1 Experimental setup used for all experiments. The bean leaf square was considered a closed arena; because neither the predator nor the prey could escape, the total number of prey killed within the arena was considered the daily prey consumption of the predator.

Fig. 2 (A) The average daily consumption of *Tetranychus urticae* eggs and larvae by female *Amblyseius andersoni* when both prey stages were provided together. Asterisks above the pairs of bars indicate significant differences between the two stages of the same species (Wilcoxon signed-rank test, $P < 0.05$). (B) The average daily consumption of *T. urticae* larvae and *Frankliniella occidentalis* first-instar larvae by female *A. andersoni* when both prey were provided together.

Fig. 3 Prey preferences of female *Amblyseius andersoni* when provided with different prey compositions. β_1 represents the prey preference of *A. andersoni* for *Tetranychus urticae* eggs when both *T. urticae* eggs and larvae were provided; β_2 represents the prey preference of *A. andersoni* for *T. urticae* larvae when both *T. urticae* larvae and *Frankliniella occidentalis* first-instar larvae were provided; β_3 represents the prey preference of *A. andersoni* for *T. urticae* larvae when both *T. urticae* larvae and frozen *F. occidentalis* first-instar larvae were provided.

Fig. 4 The average daily consumption of *Frankliniella occidentalis* first-instar larvae that were frozen and those that were not frozen by female *Amblyseius andersoni* when both the prey were provided together. Asterisks above the pairs of bars indicate significant differences between frozen and non-frozen *F. occidentalis* (Wilcoxon signed-rank test, $P < 0.05$).

Fig. 5 The average daily consumption of *Tetranychus urticae* larvae and frozen or non-frozen *Frankliniella occidentalis* first-instar larvae by female *Amblyseius andersoni*. In the Frozen group, *T. urticae* larvae were simultaneously provided with frozen *F. occidentalis* first-instar larvae, whereas in the Control group, *T. urticae* larvae were simultaneously provided with non-frozen (live) *F. occidentalis* first-instar larvae. Asterisks above the bars indicate significant differences between the same species from the different treatment groups (unpaired *t*-test, $P < 0.05$).

Fig. 6 Prey preferences relative to the ratio of *Tetranychus urticae* larvae and *Frankliniella occidentalis* first-instar larvae offered to female *Amblyseius andersoni*.

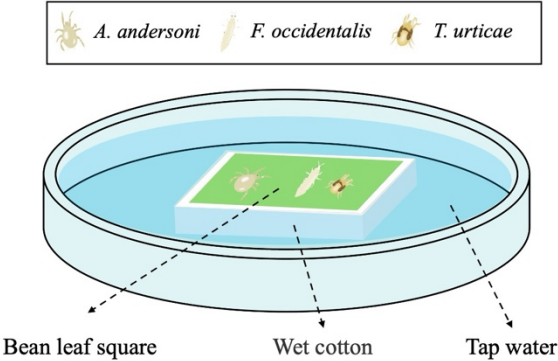
Fig. 7 The average daily consumption by female *Amblyseius andersoni* on different ratios of *Tetranychus urticae* larvae and *Frankliniella occidentalis* first-instar larvae. Boxplots present mean quartiles and interquartile range. Different uppercase letters indicate significant differences in the consumption of *T. urticae* larvae (ANOVA, $P < 0.05$); different lowercase letters indicate significant differences in the consumption of *F. occidentalis* first-instar larvae (Kruskal–Wallis test, $P < 0.05$).

Fig. 8 Prey preferences of female *Amblyseius andersoni* when provided with *Tetranychus urticae* larvae and *Frankliniella occidentalis* first-instar larvae at different temperatures. Different uppercase letters indicate significant differences at different temperatures (Kruskal–Wallis test, $P < 0.05$).

Fig. 9 The average daily consumption of *Tetranychus urticae* larvae and *Frankliniella occidentalis* first-instar larvae by female *Amblyseius andersoni* at different temperatures.

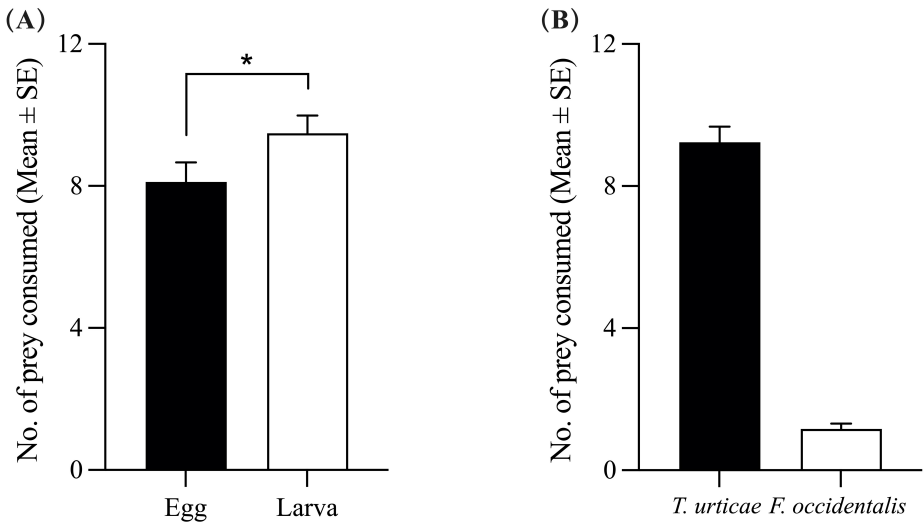
582 Boxplots present mean quartiles and interquartile range. Different uppercase letters indicate
583 significant differences in the consumption of *T. urticae* larvae (ANOVA, $P < 0.05$); different
584 lowercase letters indicate significant differences in the consumption of *F. occidentalis* first-
585 instar larvae (Kruskal–Wallis test, $P < 0.05$).

586 **Fig.1**



587

588 **Fig.2**



589

Fig.3

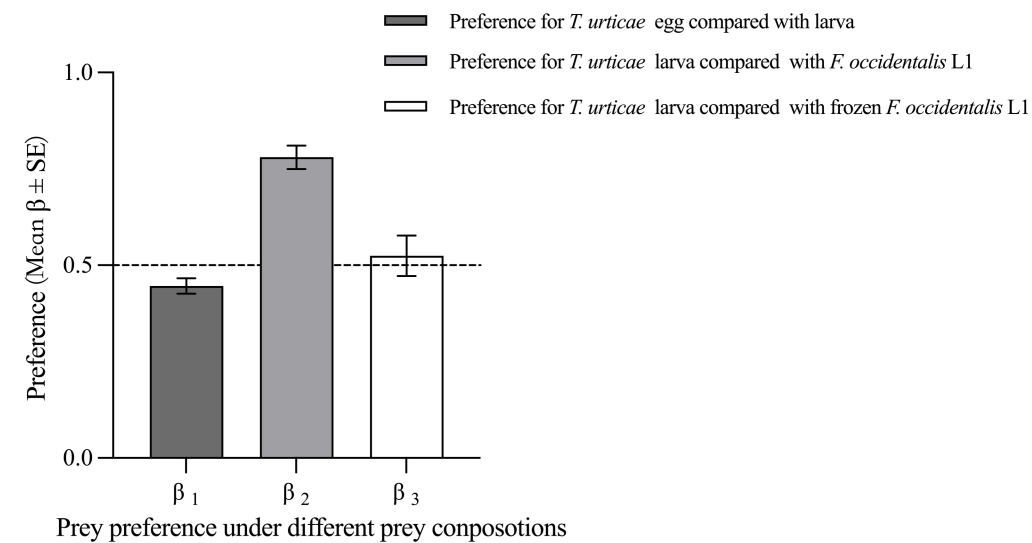


Fig.4

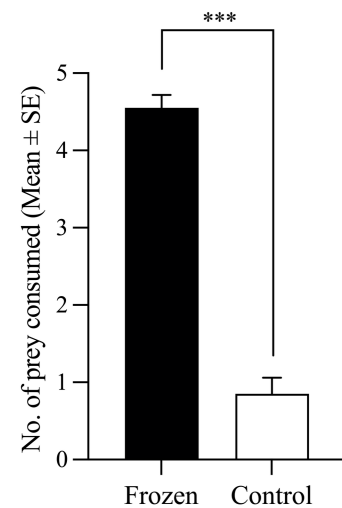


Fig.5

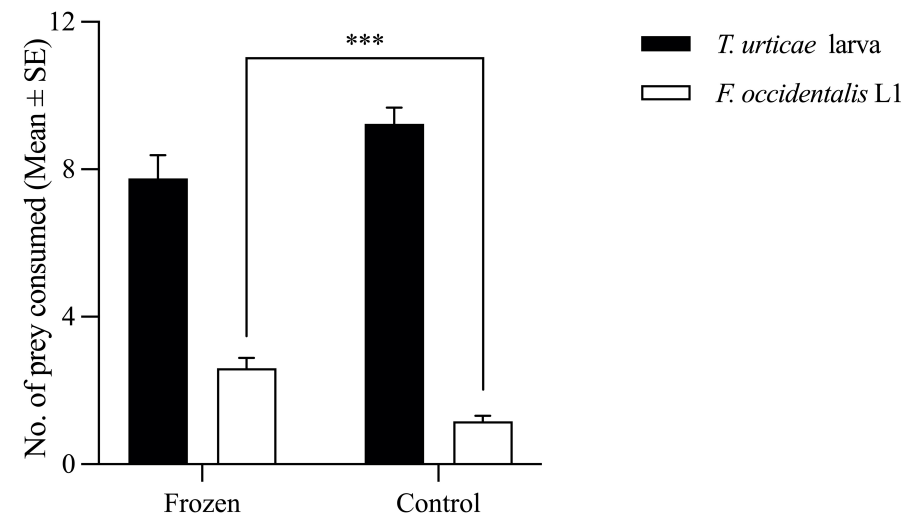


Fig.6

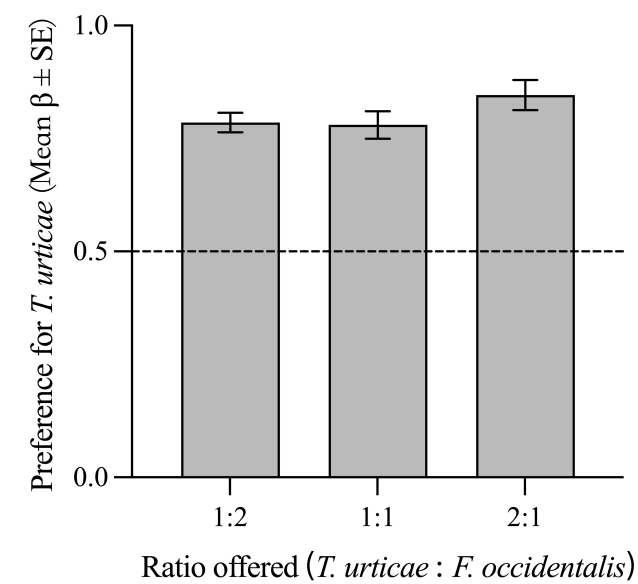


Fig.7

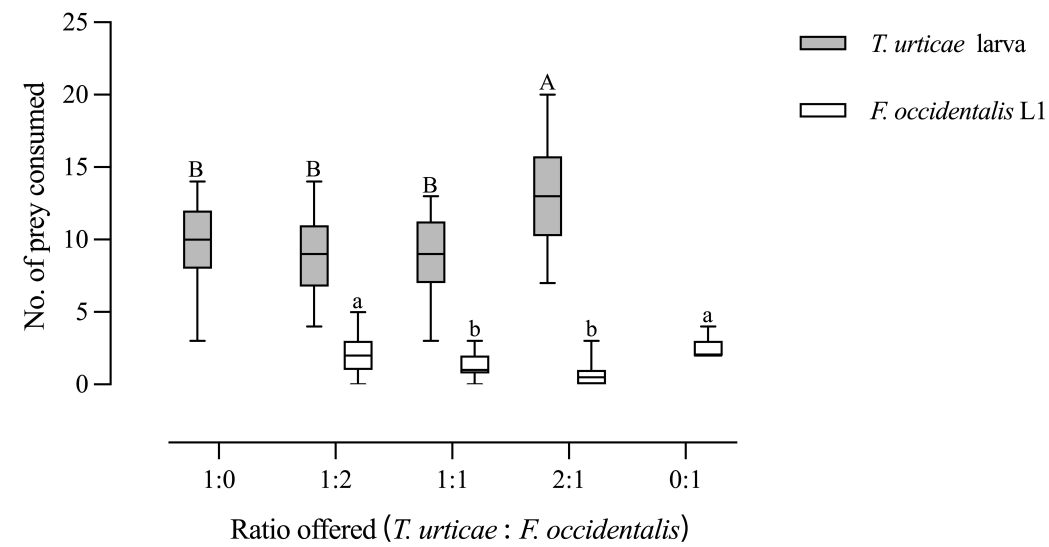
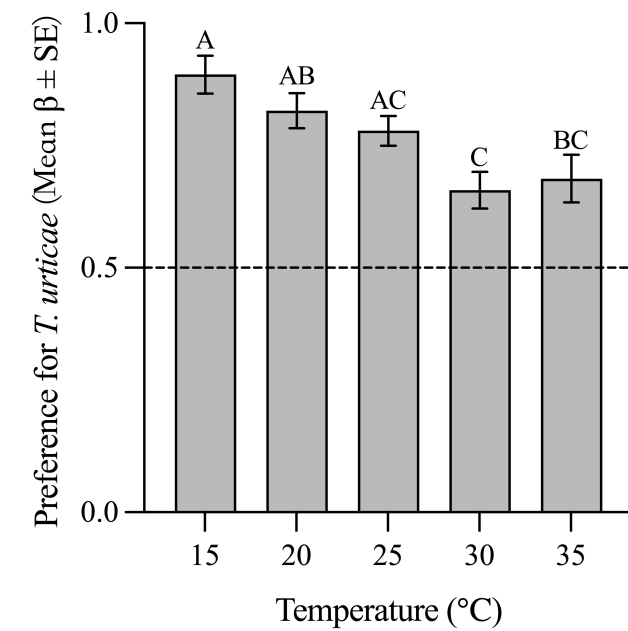
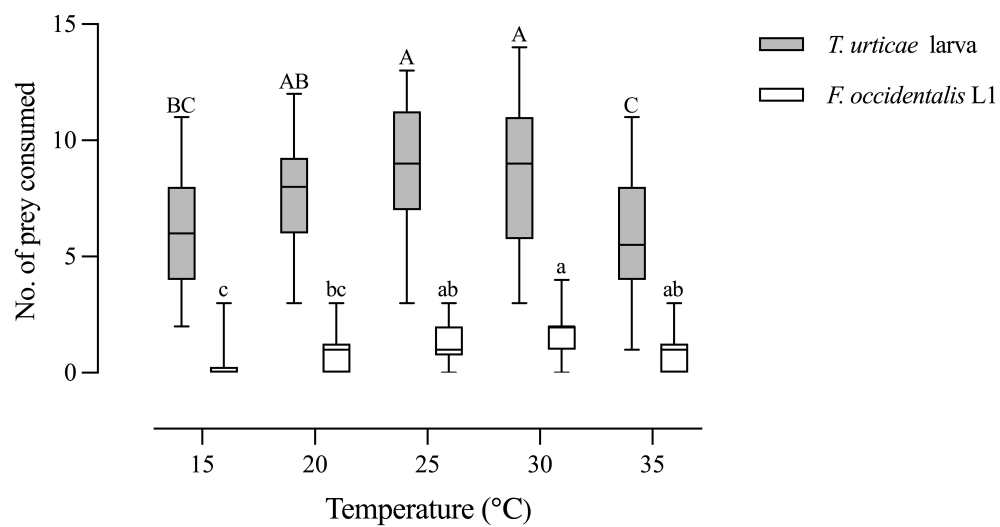


Fig.8



605 **Fig.9**



606