J. Insect Biodiversity 78 (1): 021–036
https://www.mapress.com/jib

Article

ISSN 2538-1318 (print edition)
J. Insect Biodiversity
ISSN 2147-7612 (online edition)

https://doi.org/10.12976/jib/2026.78.1.6
http://zoobank.org/urn:lsid:zoobank.org:pub:2482C514-57EE-4362-AD95-6D4DF6F6F090

Development and reproductive biology of *Buchananiella whitei* (Hemiptera: Anthocoridae) reared on different diets

YUZHI GONG[1,4†], KESHI ZHANG[1,2,5†], QIANG XUAN[3,6†] & ZHI-QIANG ZHANG[1,2,7*]

[1]*Bioeconomy Science Institute, 231 Morrin Road, Auckland 1072, New Zealand.*
[2]*School of Biological Sciences, University of Auckland, 3A Symonds Street, Auckland 1010, New Zealand.*
[3]*State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China; University of Chinese Academy of Sciences, Beijing 100049, China.*
[4] *Gongy@landcareresearch.co.nz; https://orcid.org/0009-0005-9213-7673*
[5] *Zhangk@landcareresearch.co.nz; https://orcid.org/0000-0002-9731-078X*
[6] *qxuan@nigpas.ac.cn; https://orcid.org/0000-0003-3063-9713*
[7] *zhangz@landcareresearch.co.nz; https://orcid.org/0000-0003-4172-0592*
**Corresponding author*
[†]Authors of equal contribution

Abstract

Buchananiella whitei Reuter (Hemiptera: Anthocoridae) is a native New Zealand predator that has recently been commercialised for the biological control of various arthropod pests. However, no detailed biological information has been reported for this species. This study describes its life history, development, and some oviposition when reared on three different diets—frozen moth eggs of *Ephestia kuehniella* (Lepidoptera: Pyralidae); frozen mixed stages of *Carpoglyphus lactis* (Sarcoptiformes: Carpoglyphidae); and live mixed stages of *C. lactis*. All three diets supported complete development, but individuals fed live *C. lactis* or frozen moth eggs attained significantly larger adult body sizes than those reared on frozen *C. lactis*. Developmental duration, hatch rate, and survival did not differ significantly among diets. Between 15% and 23% of individuals developed through six (rather than the usual five) nymphal instars, representing the variable instar number within the Anthocoridae. Adult females were larger than males across all treatments. Oviposition occurred only when females were provided with live *C. lactis*, and increased markedly when relative humidity was reduced (from 80% ± 5% to 26% ± 4%), suggesting that environmental moisture strongly influences reproduction. These results support our hypotheses, demonstrating that live *C. lactis* is a suitable and cost-effective factitious prey for rearing *B. whitei*, and they provide the first detailed biological description of this species. The discovery of humidity-dependent oviposition and variable instar number highlights developmental plasticity within the Anthocoridae and offers insights for optimising mass-rearing systems and improving the use of *B. whitei* in New Zealand biological control programmes.

Key words: *Carpoglyphus lactis*, Anthocoridae, biological control, insect, minute pirate bug, mite, life-history traits

Introduction

Biological control, a key component of sustainable agriculture, uses natural enemies—including parasitoids, predators, and pathogens—to regulate pest populations (Baker *et al.* 2020; Beretta *et al.* 2022; Jaiswal *et al.* 2022). Among these agents, insect natural enemies such as parasitoid wasps, leaf-feeding beetles, stem-galling moths, and pirate bugs are particularly effective against a wide range of agricultural pests, including aphids, psyllids, thrips, and whiteflies as well as weeds (Dhileepan 2001; Chen & Stansly 2014; Prado *et al*. 2015; Herrick *et al.* 2021). The minute pirate bugs (Hemiptera: Anthocoridae) are widely used as biological control agents, especially those belonging to the genus *Orius*. *Buchananiella whitei* Reuter,1884 (Hemiptera: Anthocoridae) is a species native to New Zealand, distributed across various regions of the country (Larivière & Larochelle 2014). This species is commercially available in New Zealand for the potential control of arthropod pests, like thrips (Workman & Martin 2002; X. Li & Zhang 2026). Laboratory observations have also shown that *B. whitei* can prey on all developmental stages of western flower thrips *Frankliniella occidentalis* (Pergande, 1895) (X. Li & Zhang 2026) and the spider mite *Tetranychus evansi* Baker & Pritchard, 1960 (L. Li & Zhang 2026).

Received: 20 Nov. 2025; Accepted by Jian-Feng Liu: 24 Dec. 2025; published: 6 Jan. 2026

The increasing use of predatory insects in biological control has intensified the need to optimise rearing systems with an emphasis on cost-effectiveness (Van Lenteren 2012; Huynh *et al.* 2021; Parra & Coelho 2022). Because rearing biocontrol agents on natural prey is often expensive and technically demanding, mass production typically relies on factitious (i.e. commercially reared) prey or artificial diets (Riddick 2009; Song *et al.* 2019; Tung *et al.* 2022; Zhu *et al.* 2023). Such alternative food sources can also sustain predator populations in cropping systems during periods of prey scarcity (Ogawa & Osakabe 2008; Deere *et al.* 2024).

The Mediterranean flour moth *Ephestia kuehniella* Zeller, 1879 (Lepidoptera: Pyralidae) is a well-known pest of starch-rich stored products such as flour and grains (Pakyari *et al.* 2019). Nevertheless, its eggs have been widely used as factitious prey for the mass rearing of predators (Hamasaki & Matsui 2006; Navarro-Campos *et al.* 2016; Pakyari *et al.* 2019), including *B. whitei* (C. Thompson, Bioforce limited, Pers. Comm.). When frozen, these eggs can be stored for extended periods without losing their value as alternative food (Lenteren & Tommasini 2003), although their high cost remains a major limitation.

The dried fruit mite *Carpoglyphus lactis* Linnaeus, 1758 (Acari: Carpoglyphidae) has been extensively used as factitious prey for rearing predatory mites (Ji *et al.* 2015; Liu *et al.* 2024a; Wang *et al.* 2024; Cao *et al.* 2025). Given the high expense of *E. kuehniella* eggs for rearing *B. whitei* and the limited understanding of the basic biology of this native species, we evaluated several life-history traits—including immature development, size at maturity, and short-term oviposition—when reared on both live and frozen *C. lactis*, in comparison with frozen moth eggs.

The objectives of this study were to provide basic biological information on *B. whitei*, identify a more economical rearing method for this predator, examine potential differences in the nutritional quality of live versus frozen *C. lactis*, and document its life history traits and morphological characteristics. We hypothesised that *C. lactis* could serve as a partial substitute for moth eggs as prey, and that live *C. lactis* would prove more effective than frozen mites for rearing *B. whitei*.

Material and methods

Study subjects and rearing conditions

Buchananiella whitei eggs and *C. lactis* were initially obtained from Bioforce Limited (New Zealand). The culture of *C. lactis* was maintained in 250 mL plastic containers, each with a mesh-covered hole in the lid to allow ventilation while preventing mite escape. Cultures were reared on a mixture of icing sugar (Chelsea, New Zealand) and dry yeast pellets (Goodman Fielder Limited, New Zealand). The *C. lactis* cultures were kept in Plexiglass cabinets at 24°C ± 1°C, 80% ± 5% relative humidity (RH), and a 16:8 h light:dark photoperiod (Zhang & Zhang 2021; Wang *et al.* 2024).

Frozen *C. lactis* were prepared following Liu *et al.* (2024a) and stored at −18°C for approximately one month. Eggs of the *moth E. kuehniella* were purchased in bulk (Bioforce, New Zealand) and stored under the same conditions. Before being offered to predators, both *C. lactis* and *moth* eggs were thawed at room temperature (c. 25°C) for about 30 min.

The rearing cells consisted of two Plexiglass slides, four layers of filter paper, a leaf disc, and a piece of food wrap with five perforations made using insect pins (size 000) (Wang *et al.* 2024). Leaf discs of black nightshade (*Solanum nigrum* Linnaeus, 1753) collected from the Manaaki Whenua – Landcare Research Group (MWLR) campus of the Bioeconomy Science Institute (Auckland, New Zealand) was used in the rearing set-up (Zhang *et al.* 2025). Before use, black nightshade leaves were soaked in filtered water for 30 min and rinsed three times. Leaf discs (20 mm diameter) were cut with a hole punch, avoiding midribs and primary veins to ensure an even distribution of trichomes (Zhang *et al.* 2025).

Experimental procedure

Diet treatments: Unhatched eggs of *B. whitei* (unknown age) individually reared in modified rearing cells. Each individual was assigned to one of three diet treatments: i) previously frozen moth eggs (Treatment A); ii) previously frozen mixed-stage *C. lactis* (Treatment B); iii) live mixed-stage *C. lactis* (Treatment C). Each treatment included 30 replicates, and food was provided *ad libitum*. Individuals of *B. whitei* were checked daily to record developmental progress until emergence as adults, and exuviae were removed after each moult. Filter papers were kept moist with filtered water to maintain leaf freshness. New rearing cells were prepared every 5 days to ensure a continuous supply of food and fresh leaf material, and individuals were transferred using a fine, damp brush (size 6).

Newly emerged adults were gently placed ventral side up under a sheet of food wrap and examined under a stereo

microscope to determine sex. Males were identified by the presence of an asymmetrical pygophore with a short, straight paramere visible on the terminal abdominal sternites, whereas females lacked this structure (Fig. 1E–H). The apical one-third of the second and third antennal segments is darker in females, while in males more than three-quarters of these segments are dark (Fig. 1A–D). In addition, the third antennal segment of the male is slightly thicker than that of the female. Males are also generally smaller than females (Fig. 2A). Body length, thorax width, and abdomen width were measured for each adult prior to pairing using NIS-Elements software (version 5.10).

Mating experiments: These were carried out sequentially under controlled conditions, and using different grouping (individual pairing and group rearing) set-ups as follows: individual pairing (1) Set-up 1: one adult male and one adult female from the same diet treatment were paired in a 3.02 mL leaf-disc rearing cell (Wang *et al.* 2024) for 7 days to record fecundity (number of laid eggs) (10 pairs in Treatment A, 9 in B, and 10 in C) at 25 ± 1 °C and 80 ± 5 % RH. Grouping rearing (1) Set-up 2: four pairs of adults were introduced into a 79.89 mL bottle (with 2 bottles per treatment) and maintained for 7 days under the same conditions as in (1). Grouping rearing (2) Set-up 3 Four pairs of adults from previous 1v1 mating were then transferred onto 23.77 mL Petri dishes (2 dishes per treatment) for an additional 7 days to monitor oviposition. Group rearing (3) Set-up 4: the Petri dishes were moved to a cooler environment (14°C, 26% ± 4% RH) for 7 days, and fecundity was recorded for all stages.

For both diet and mating experiments, the treatments provided with moth eggs and frozen *C. lactis*, food was replaced every 2–3 days (Liu *et al.* 2024b), while in the live *C. lactis* treatment, mites were replenished at the same interval. Any eggs produced by mated females from mating experiment were individually transferred to clean small cells for hatching observation.

Another block of 30 eggs was individually reared in separate rearing cells and fed exclusively on moth eggs. The developmental and morphological characteristics of each instar were monitored and recorded daily. At each instar, one randomly selected individual was frozen for morphological photography.

Statistical analysis

All statistical analyses were conducted in R (R Core Team 2024) using RStudio (version 2023.12.1). Data visualisation was performed with the **ggplot2** package (version 3.4.3) (Wickham 2016). Hatching rate and survival rate were analysed using logistic regression with a binomial distribution. An Aligned Rank Transform (ART) analysis of variance (ANOVA) was used for developmental duration, body length, thorax width, and abdomen width because the data were numeric and non-normally distributed. Data distributions and model overdispersion were verified prior to analysis. For developmental duration and morphological measurements, results are presented as means ± standard errors of the mean (SEMs). Statistical significance was accepted at alpha = 0.05.

Results

Morphological information

Eggs: Eggs are oblong-oval in shape, with the opercular region located at one end (Fig. 3). The eggshell surface bears irregular protuberances, giving it a rough texture. The operculum is circular with a slightly convex central region, covered with sharply edged engraved reticulations most distinct in the centre. Eggs are deposited loosely and adhere to substrates via an adhesive secretion. Freshly laid eggs are semi-transparent and creamy white, gradually turning reddish as hatching approaches. In advanced stages, the eye spots and abdominal scent glands of the embryo become distinctly darker red.

First instar nymph: Newly hatched nymphs are reddish, with abdominal scent glands visible as darker red spots (Fig. 4). The antennae and legs are semi-transparent yellowish.

Second instar nymph: Darker red than the first instar, with abdominal scent glands less distinct (Fig. 5). The body size is noticeably larger, and a pair of long bristles appears at the abdominal apex.

Third instar nymph: A deeper red than the previous instar, with abdominal scent glands no longer visible (Fig. 6). Body size increases further, and small wing buds become visible. The eyes are more developed, and the abdominal bristles elongate.

Fourth instar nymph: Further deepening in red pigmentation (Fig. 7). Wing buds enlarge and darken toward the abdominal tip. The eyes continue to develop, and body size increases.

Fifth instar nymph: General colour and morphology resemble the previous stage, but the wing pads are now fully developed and extend beyond the thoracic region (Fig. 8). The compound eyes are larger and more complex.

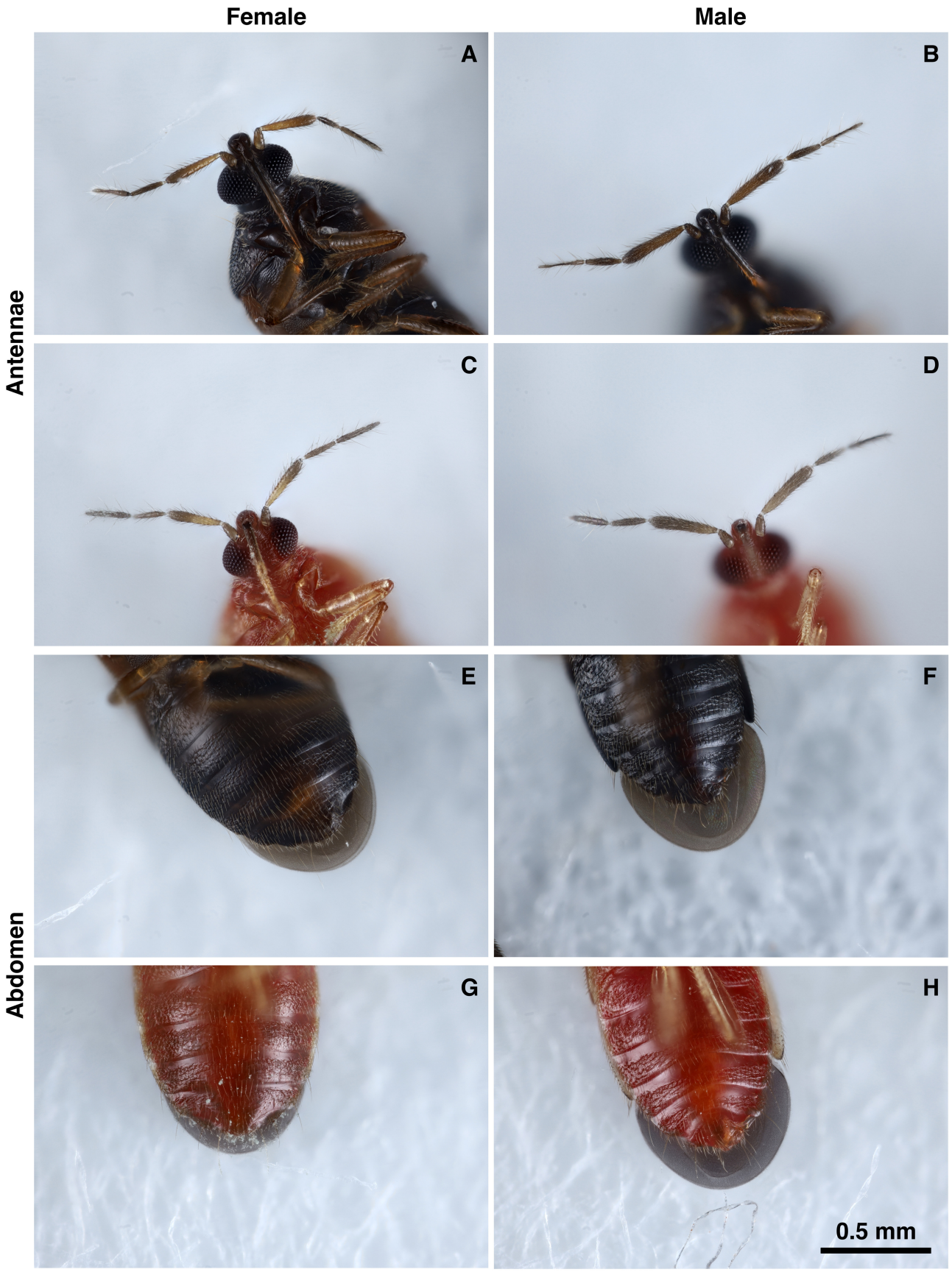

Figure 1. Abdominal sexual features of *Buchananiella whitei*. **A,** adult female antenna; **B,** adult male antenna; **C,** newly emerged adult female (within one day) antenna; **D,** newly emerged adult male (within one day) antenna; **E,** adult female abdomen; **F,** adult male abdomen; **G,** newly emerged adult female (within one day) abdomen; **H,** newly emerged adult male (within one day) abdomen.

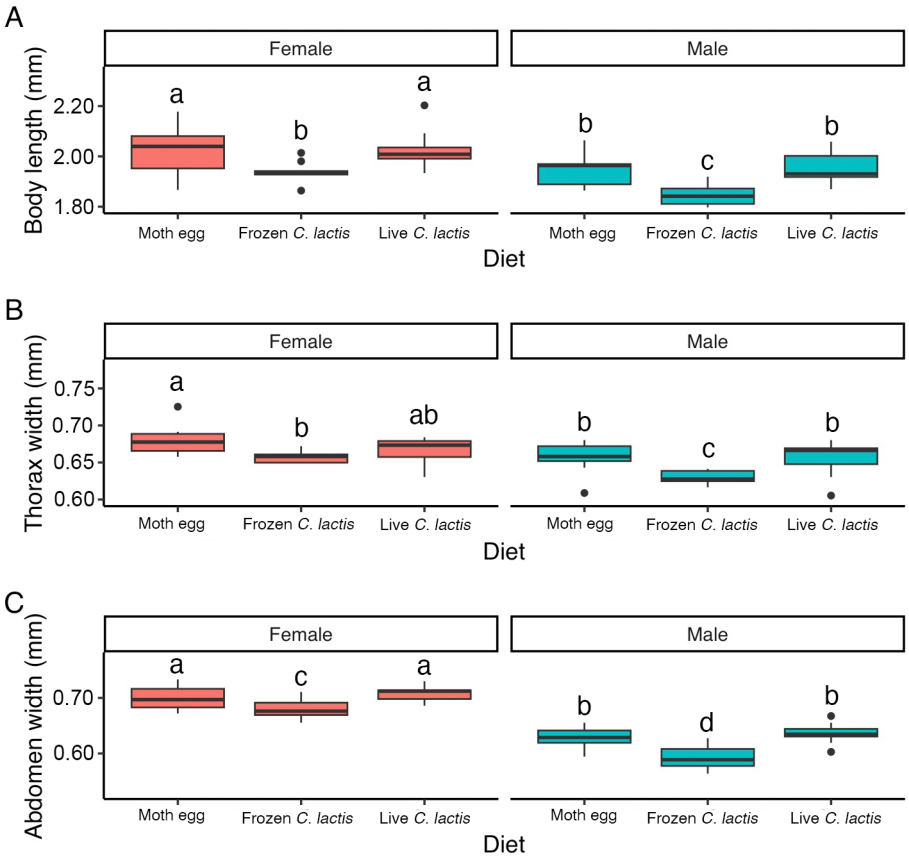

Figure 2. Box plot of female and male adult sizes of *Buchananiella whitei* reared on different prey (moth egg, frozen *C. lactis* and live *C. lactis*); **A,** body length; **B,** thorax width; **C,** abdomen width; box plots show the median (horizontal line), interquartile range (box), and minimum and maximum values within 1.5 × IQR (whiskers); dots represent outliers. Boxes with different letters above denote significant differences from ART ANOVA pairwise comparisons (a,b,c).

Figure 3. Eggs of *Buchananiella whitei* at different stages. From left to right: freshly laid egg, developing egg with eye spots and abdominal scent glands appearing; egg before hatching with three red dorsal straps appearing; eggshell after hatching. Photo taken using a camera with a 10× adapted lens.

Figure 4. first instar nymph of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

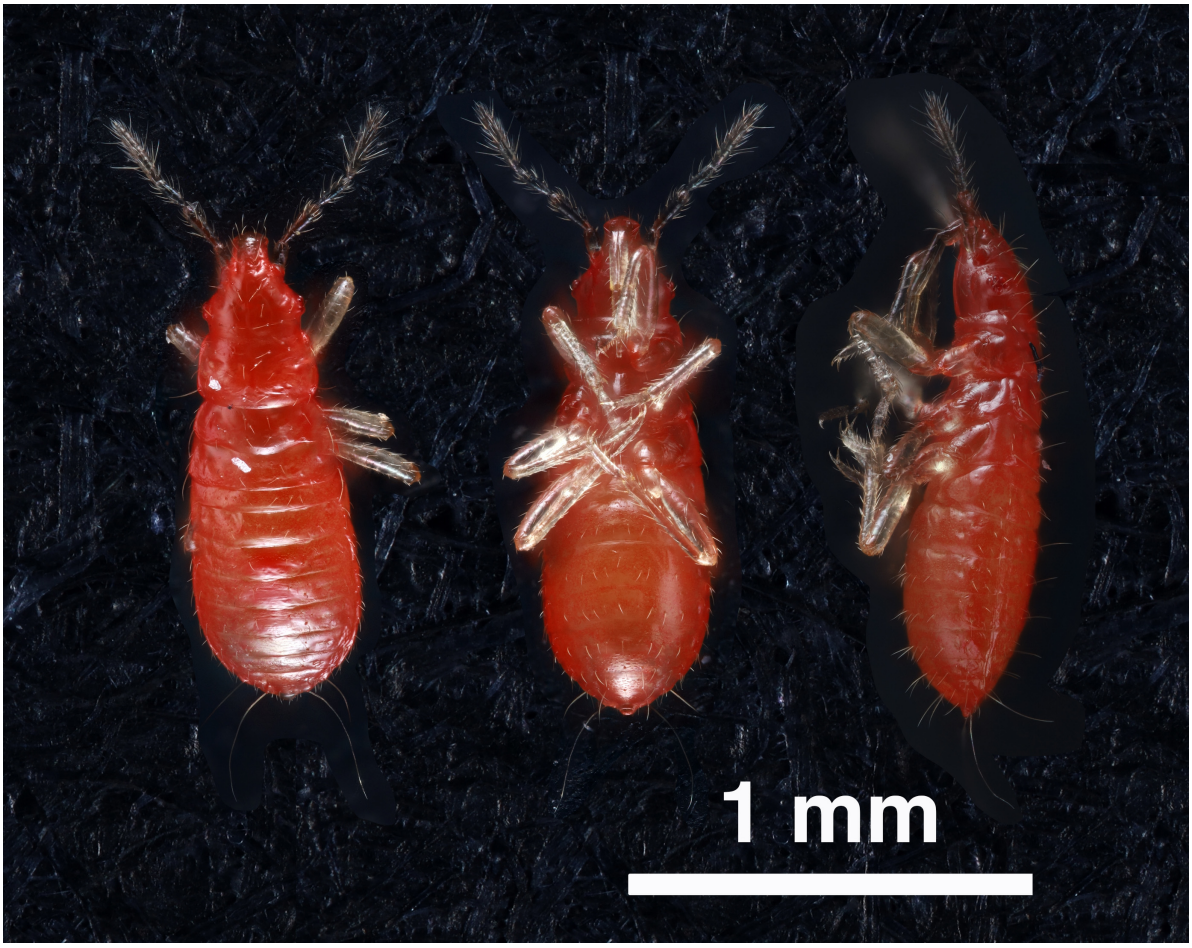

Figure 5. Second instar nymph of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

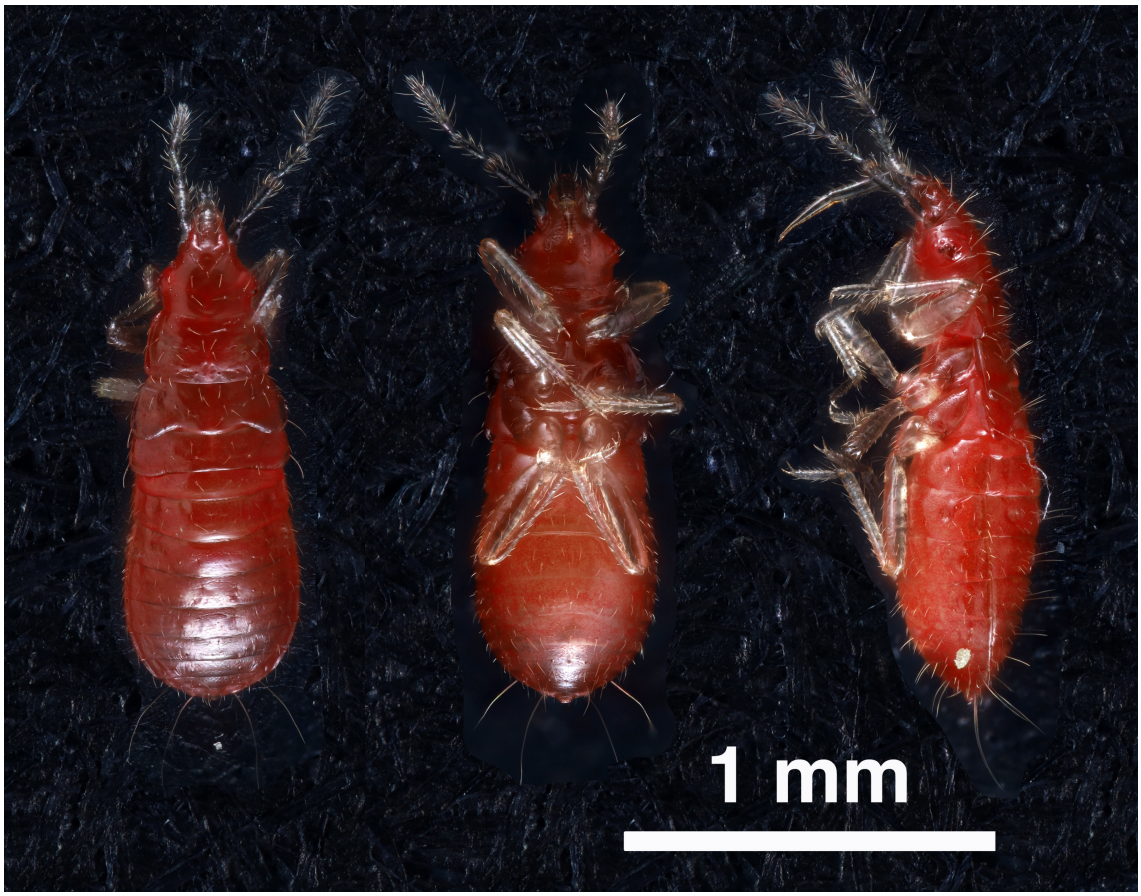

Figure 6. Third instar nymph of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

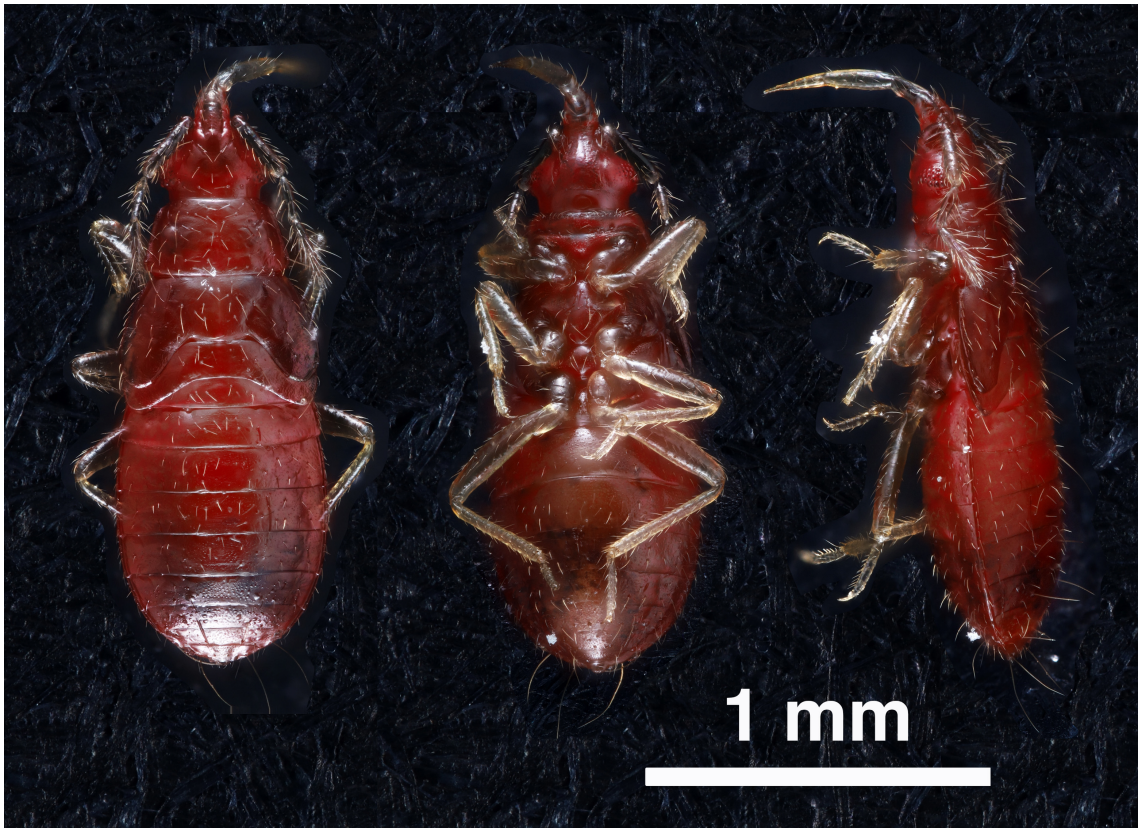

Figure 7. Fourth instar nymph of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

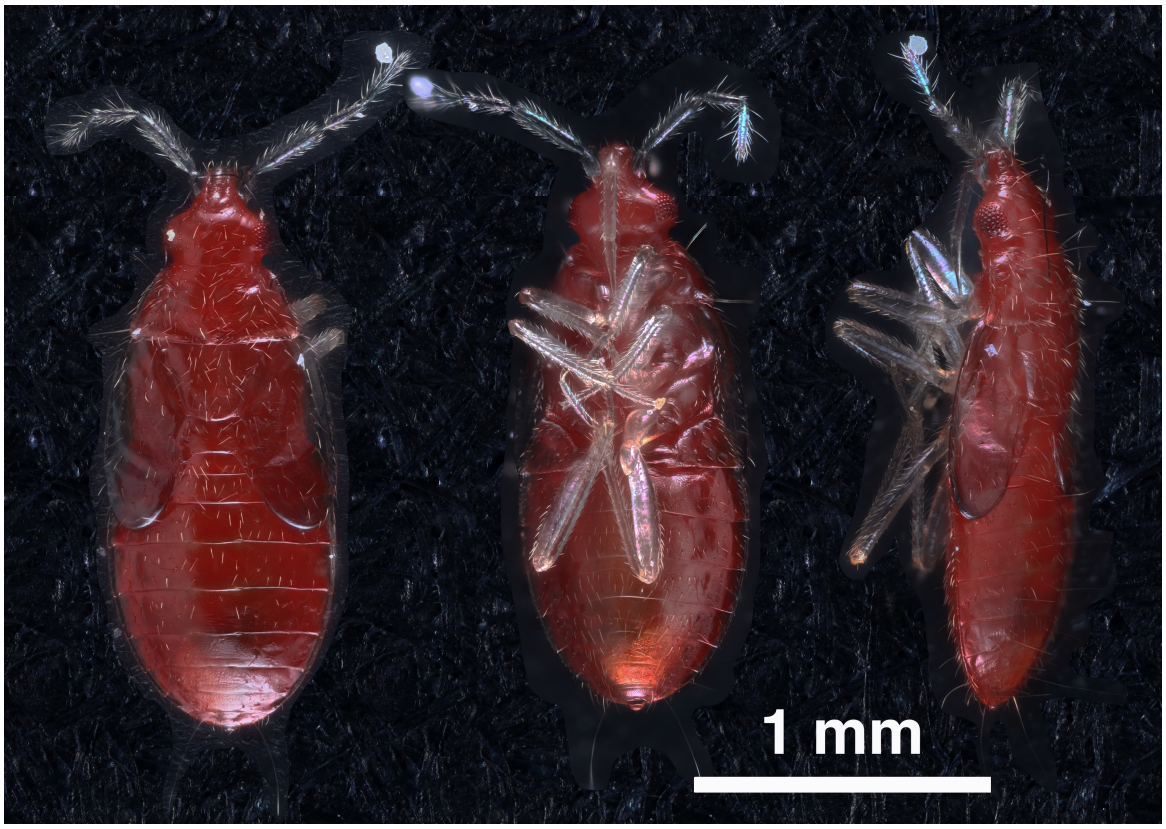

Figure 8. Fifth instar nymph of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

Adult: Newly emerged adults are reddish, with wing tips appearing blackish (Figs 9–10). Within a day, the entire body darkens to blackish brown (Figs 11–12). The final rostral segment is curved and pointed, and the legs are yellowish brown. In males, the terminal abdominal sternites bear an asymmetrical pygophore with a short, straight paramere. Females are larger than males and possess a small opening (omphalus) medially on abdominal sternite VII. The mean body length, thorax width, and abdomen width of males are 1.92 mm, 0.65 mm, and 0.62 mm, respectively, whereas females measure 2.00 mm, 0.67 mm, and 0.70 mm.

Hatching, survival and development

Egg hatching rate (logistic regression: Wald $\chi^2 = 1.534$, $df = 2$, $p = 0.464$), survival to maturity (logistic regression: Wald $\chi^2 = 3.418$, $df = 2$, $p = 0.181$), and total developmental duration (ART ANOVA: $F_{2,72} = 1.789$, $p = 0.175$) were not significantly influenced by diet or sex of *B. whitei* (see details in Table 1).

Table 1. Biological parameters of female and male of *Buchananiella whitei* reared on different prey treatments. The bracketed (*n*) indicates the number of individuals undergoing a 6th instar.

				Duration of each nymph stage (days)							
Treatment	**Sex**	***N***	**Hatch (%)**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th (*n*)**	**1st instar–Adult (days)**	**Survive (%)**
Moth egg	Female	29	96.6	3.2 ± 0.1	2.8 ± 0.1	3.1 ± 0.2	3.4 ± 0.2	6.6 ± 0.5	7.0 ± 0.0 (2)	20.4 ± 0.5	92.6
	Male			3.1 ± 0.1	2.5 ± 0.1	3.0 ± 0.3	3.4 ± 0.4	6.8 ± 0.4	5.0 ± 2.0 (3)	19.1 ± 0.3	
C. lactis (frozen)	Female	29	89.7	3.2 ± 0.3	3.4 ± 0.3	3.2 ± 0.4	4.9 ± 0.4	7.0 ± 0.9	7.5 ± 0.5 (3)	23.2 ± 0.5	80.0
	Male			3.3 ± 0.2	3.8 ± 0.4	3.3 ± 0.4	4.4 ± 0.2	8.3 ± 0.3		23.1 ± 0.5	
C. lactis (live)	Female	27	88.9	3.0 ± 0.0	2.6 ± 0.3	2.3 ± 0.3	3.6 ± 0.4	5.8 ± 0.7	6.5 ± 0.3 (5)	19.1 ± 0.5	95.7
	Male			2.9 ± 0.1	2.4 ± 0.2	3.2 ± 0.4	4 ± 0.5	7.4 ± 0.2		19.4 ± 0.4	

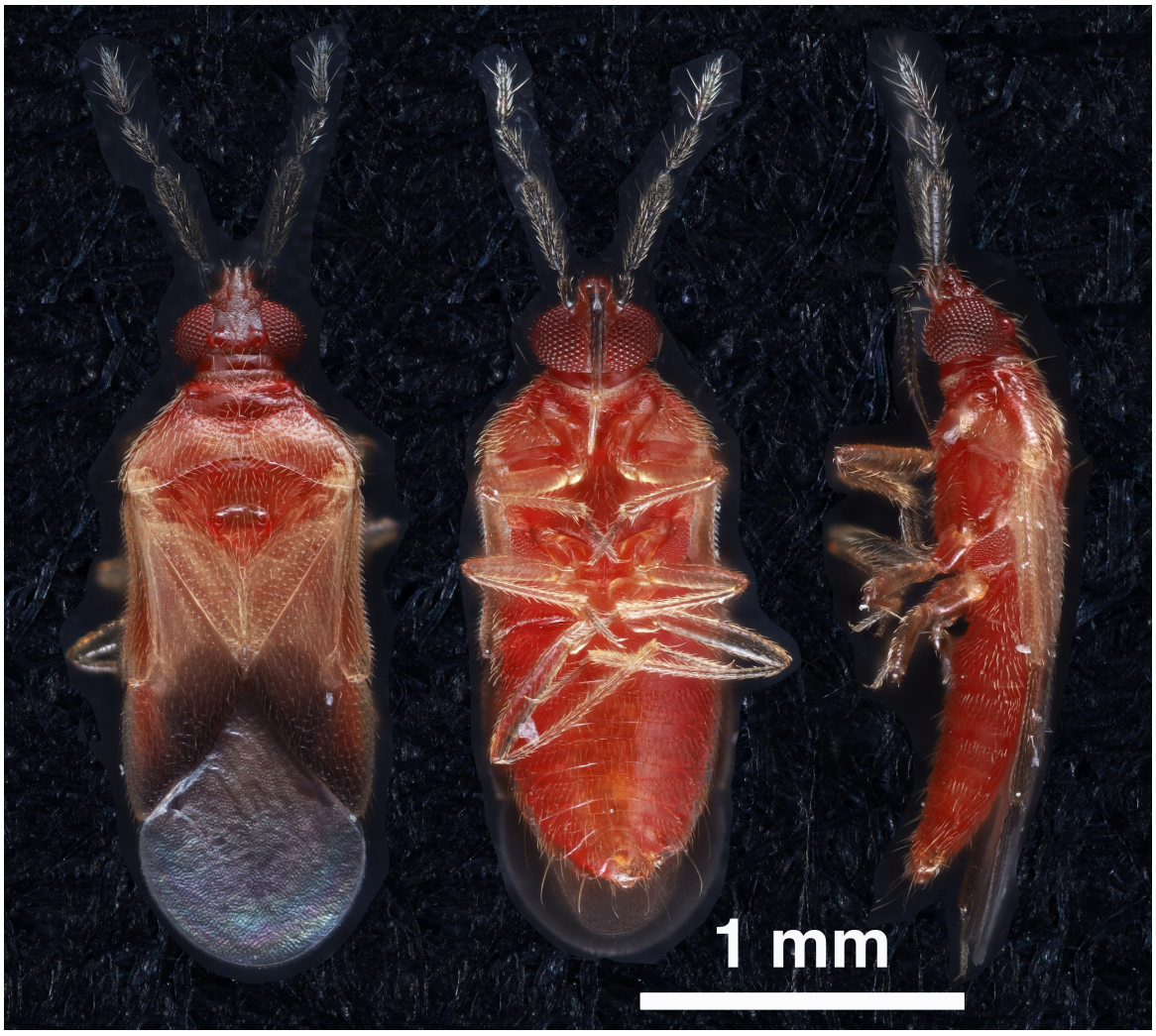

Figure 9. Newly emerged male of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

Effects of rearing diet on number of instar and size at maturity

Among individuals reared on different diets, 5 of 25 (20%) in the moth-egg treatment, 3 of 20 (14%) in the frozen *C. lactis* treatment, and 5 of 21 (23%) in the live *C. lactis* treatment developed through six nymphal instars. The number of nymphal instars taken to reach maturity (*i.e.* 5 or 6) significantly affected abdomen width (ART ANOVA: $F_{1,56}$ = 5.295, p = 0.025), but not body length ($F_{1,56}$ = 0.104, p = 0.749) or thorax width ($F_{1,56}$ = 1.348, p = 0.251).

Adult morphometrics

Body length (ART ANOVA: $F_{2,56}$ = 15.503, p < 0.001), thorax width ($F_{2,57}$ = 13.443, p < 0.001), and abdomen width ($F_{2,57}$ = 16.489, p < 0.001) differed significantly among diet treatments. Adults reared on live *C. lactis* and moth eggs were significantly larger than those reared on frozen *C. lactis* (Fig. 2). However, no significant size differences were observed between individuals from the live *C. lactis* and moth egg treatments.

Females of *B. whitei* were consistently larger than males across all prey treatments in body length (ART ANOVA: $F_{1,56}$ = 25.781, p < 0.001), thorax width ($F_{1,57}$ = 25.299, p < 0.001), and abdomen width ($F_{1,57}$ = 168.206, p < 0.001).

Oviposition in mating experiments

No oviposition was observed in *B. whitei* females reared on moth eggs or frozen *C. lactis* under either individual or group conditions (Set-up 1) at 25°C ± 1°C and 80% ± 5% RH (Table 2). In contrast, a single pair fed on live *C. lactis* produced 10 eggs under the same conditions. Group-rearing (i.e. bottle and Petri-dish) trials revealed a marked increase in fecundity when live *C. lactis* were provided: females laid an average of 10.0 ± 10.0 eggs in bottles after

7 days at 25°C. When transferred to Petri dishes and maintained for a further 7 days at 14°C and 26% ± 4% RH, oviposition increased to 15.0 ± 15.0 eggs. Under the same cooler conditions, females fed frozen *C. lactis* began to oviposit, producing an average of 3.5 ± 3.5 eggs. These findings indicate that oviposition in *B. whitei* was markedly enhanced when live prey was available and might also be influenced by lower temperature and humidity.

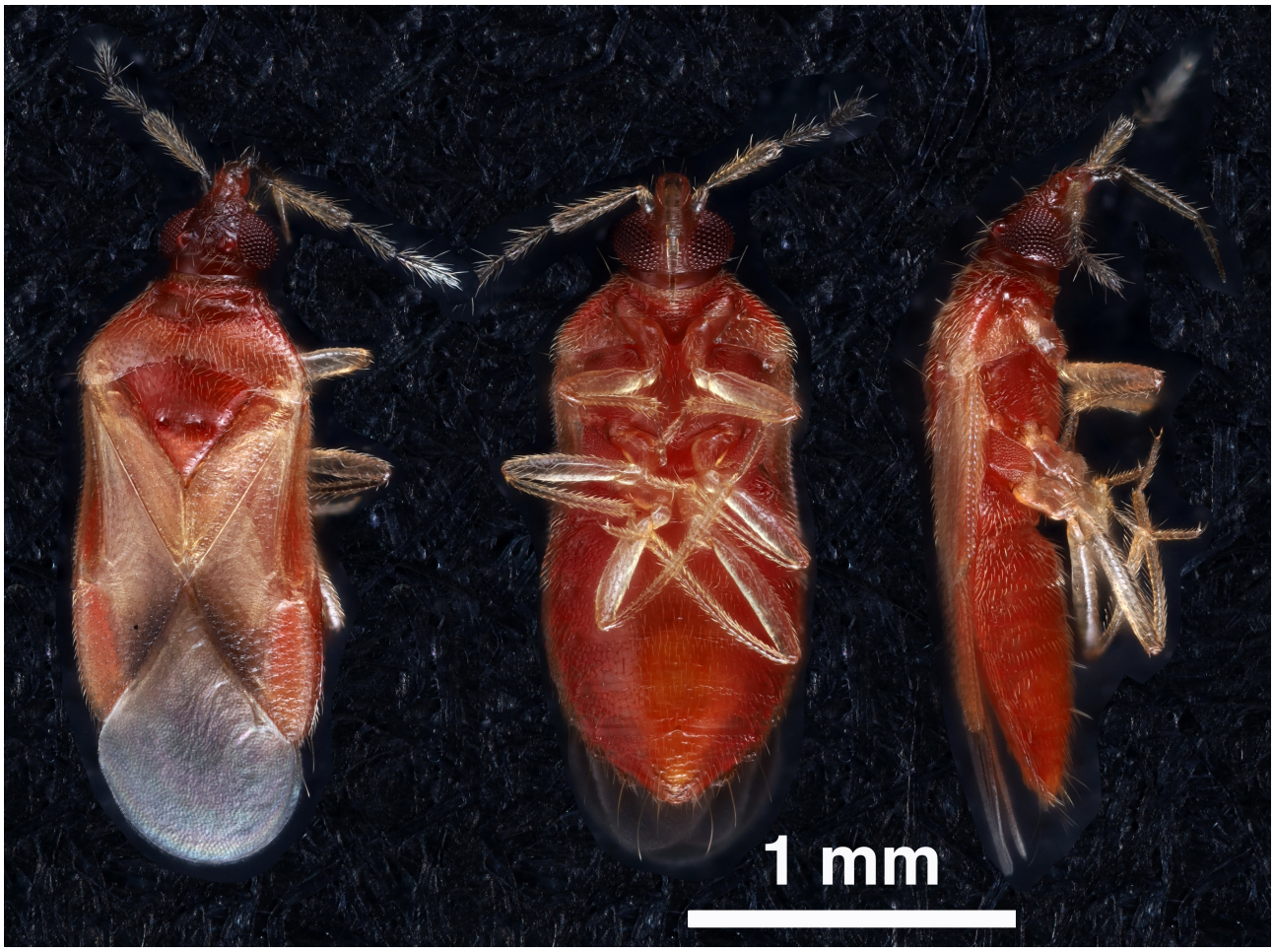

Figure 10. Newly emerged female of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

Table 2. Mean (± SEM) number of eggs laid by *Buchananiella whitei* females under different diet and rearing conditions. The number of replicates (*n*) is shown in brackets. Social rearing conditions included: (1) individual pairing—Set-up 1, (2) group rearing—Set-up 2: bottle rearing (bottle), and two different Petri-dish trials (group rearing—Set-up 3–4). Environmental rearing conditions included two different temperature and moisture conditions.[1,2] Diet treatments consisted of (A) frozen *Ephestia kuehniella* eggs (moth egg), and frozen (B) or live (C) *Carpoglyphus lactis* (all stages). Means followed by different letters denote significant differences from ART ANOVA pairwise comparisons for each diet treatment (a,b).

Diet treatment	**Individual pairing (*n*)**	**Group rearing (*n*)**		
		Bottle	**Petri-dish[a]**	**Petri-dish[b]**
A) Moth egg (frozen)	0.0 ± 0.0 (10) [a]	0.0 ± 0.0 (8) [a]	0.0 ± 0.0 (8) [a]	0.0 ± 0.0 (8) [b]
B) *C. lactis* (frozen)	0.0 ± 0.0 (9) [a]	0.0 ± 0.0 (8) [a]	0.0 ± 0.0 (8) [a]	3.5 ± 3.5 (8) [b]
C) *C. lactis* (live)	1.0 ± 1.0 (10) [a, 3]	10.0 ± 10.0 (8) [a]	0.0 ± 0.0 (8) [a]	15.0 ± 15.0 (8) [b]

[1] 25°C ± 1°C and 80% ± 5% RH.

[2] 14°C and 26% ± 4% RH.

[3] 10 eggs were produced by one pair of *B. whitei in this set-up.*

Figure 11. Male adult of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

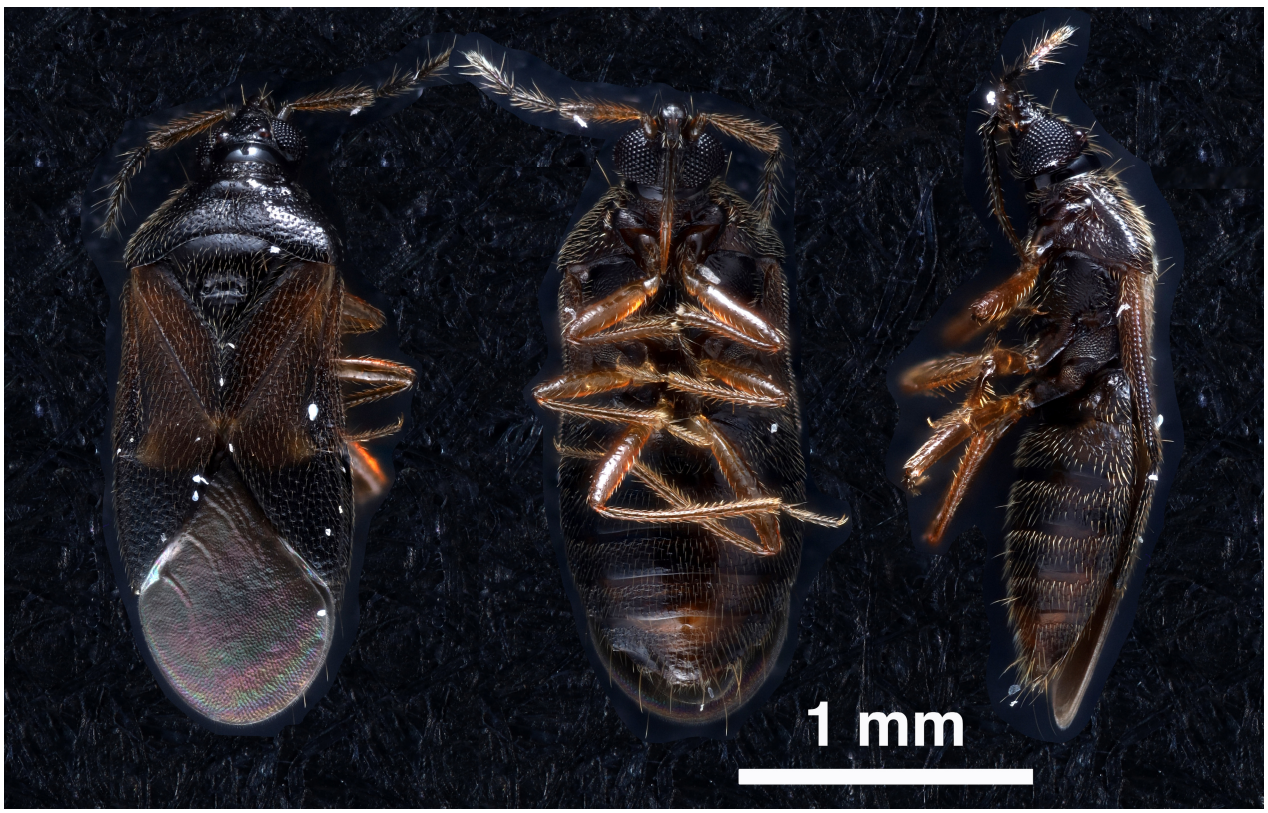

Figure 12. Female adult of *Buchananiella whitei*. From left to right: dorsal view, ventral view, and side view. Photo taken using a camera with a 10× adapted lens.

Discussion

The present study provides the first detailed account of the life history and morphology of *B. whitei*, a native New Zealand species for which no prior biological data were available (but see L. Li & Zhang 2026; X. Li & Zhang 2026 in this issue). All three diets tested supported development to adulthood, although individuals reared on live *C. lactis* and moth eggs attained larger body sizes than those fed frozen *C. lactis*. These findings indicate that live *C. lactis* is a suitable and cost-effective alternative to moth eggs for rearing *B. whitei* and may be applied in future mass-production programmes.

The genus *Buchananiella* remains poorly studied, with biological details available only for two species—*B. indica* Muraleedharan, 1977 and *B. sodalis* (White, 1878). In *B. whitei*, females were significantly larger than males, consistent with the sexual size dimorphism reported in *B. indica* and *B. sodalis* (Naseer & Abdurahman 1990; Ballal *et al.* 2016). The duration of the egg stage in *B. indica* and *B. sodalis* is typically 3–4 days, and the development of each instar stage for the first to fourth instars takes about 2–3 days. However, we observed the last instar (fifth or sixth) before emerged to adult of *B. whitei* lasted slightly longer (5–7 days) than those reported for *B. indica* and *B. sodalis* (4–6 days) (Naseer & Abdurahman 1990; Ballal *et al.* 2016). The extended duration of the final instars in *B. whitei* may be explained by several factors. First, interspecific variation within the genus could account for differences in developmental timing, as has also been observed between *Orius minutus* (Linnaeus, 1758) and *O. laevigatus* (Fieber, 1860) (Rahman *et al.* 2020). Second, environmental conditions—particularly temperature and relative humidity—may have influenced developmental rate, a phenomenon also recorded in *Anthocoris nemoralis* (Fabricius, 1794) (Yanık 2011). Finally, nutritional limitation during the final instar may have contributed to extended duration, as prey was not replenished at this stage, potentially causing food stress and delayed development—a mechanism likewise reported in *O. albidipennis* (Reuter, 1884) (Sobhy *et al.* 2010).

Both *B. indica* and *B. sodalis* complete development in five instars under similar temperatures (26°C ± 5°C and 28°C ± 1°C, respectively) but at substantially lower humidity (60 % ± 10% RH and 56% ± 7% RH). In contrast, 15% to 23% of *B. whitei* individuals in the present study underwent a sixth nymphal instar when reared at 25°C ± 1°C and 80% ± 5% RH. Variation in instar number among individuals within a species is not uncommon in insects and is often driven by environmental factors such as temperature and humidity (Archer *et al.* 1980; Esperk *et al.* 2007; Ali *et al.* 2011). To our knowledge, this species represents the first in the Anthocoridae with variable instar number which was also confirmed in another related study (L. Li & Zhang 2026 in this issue). A similar observation has been reported in another New Zealand species of a different family, *Nysius huttoni White, 1878 (Lygaeidae)*, where temperature affected the number of nymphal instars (Wei 2010). Whether the variation in *B. whitei* arose from the high humidity conditions in most of this study or from potential parental effects associated with the commercially-reared source population remains uncertain.

Our results demonstrate that *C. lactis* is an effective factitious prey for *B. whitei*, yielding comparable survival, development, and adult size to a diet of moth eggs. Moreover, the two *C. lactis* treatments were the only ones that resulted in oviposition. Although *C. lactis* has been successfully used to rear a wide range of arthropods (Yan *et al.* 2022; Amin & Khanjani 2024; Wang *et al.* 2024; Zhang *et al.* 2025), other studies have reported that live *C. lactis* performed poorly as prey (e.g. for *Orius thripoborus* (Hesse, 1940) and *O. naivashae* (Poppius, 1920)—see Bonte *et al.* (2017) in reactions to *C. lactis* may reflect inter-generic differences in feeding ecology and prey preference, as prey suitability is known to vary considerably among anthocorid genera (Lattin 1999).

Individuals reared on live *C. lactis* exhibited higher survival, faster development, and larger adult size than those fed frozen *C. lactis*, suggesting that live prey provide superior nutritional quality. Similar patterns have been observed in other predatory arthropods, including the phytoseiid mites (*Phytoseiulus persimilis* Athias-Henriot, 1957) (Xu *et al.* 2023), and heteropteran predators such as *Adalia bipunctata* (Linnaeus, 1758) (Jalali *et al.* 2009) and *Andrallus spinidens* (Fabricius, 1787) (Mohaghegh & Amir-Maafi 2007), where live or freshly killed prey enhanced growth and reproductive performance, like fecundity.

Oviposition in *B. whitei* was strongly influenced by prey type and environmental conditions. Females reared on live *C. lactis* were the only individuals that produced eggs under high-humidity conditions (25 ± 1 °C and 80 ± 5 % RH), whereas females reared on moth eggs did not oviposit under any temperature or humidity regime tested. This pattern is partly consistent with previous studies on *Orius laevigatus* (Bonte & De Clercq 2010) and *B. whitei* (L. Li & Zhang 2026), which suggested that plant material or artificial substrates may stimulate oviposition behaviour. However, in this study, leaf-disc rearing cells were used during the mating experiments, yet females reared on moth eggs still failed to lay eggs. This indicates that the absence of oviposition was unlikely to be driven solely by a lack of plant material, and instead suggests that additional oviposition substrates may be required.

For mating experiment, because only one of the 'individual pairing' (Set-up 1) resulted in egg production—and none of those eggs hatched—our Methods also included further 'group rearing' experiments (see Methods section) to test whether *B. whitei* required multiple mating events. Multiple mating is a behaviour common among arthropods (Fadamiro & Baker 1999; Pai *et al.* 2005; Omkar & Mishra 2010; Chen *et al.* 2025). When multiple pairs were introduced into a bottle (Set-up 2), fecundity increased and egg hatching commenced, although the rates remained low. Oviposition then ceased when the set-up was transferred to Petri dishes (Set-up 3), probably due to the inhibitory effect of high humidity, as reported for other insects (Mbata 1986; Broufas *et al.* 2009; Norhisham *et al.* 2013; He *et al.* 2021; Levi-Mourao *et al.* 2021). When finally transferred to Set-up 4—a cooler environment with lower humidity (14°C and 26% ± 4% RH)—both oviposition and hatching rate increased markedly.

The temperature and humidity initially chosen for this study were optimal for *C. lactis* cultures, and the pronounced inhibitory effect of high humidity on *B. whitei* reproduction was therefore unexpected. Based on previous work of *B. whitei*, *B. indica* and *B. sodalis*, the optimal conditions for *Buchananiella* species appear to be between 10°C and 31°C and 49%–70% RH (Naseer & Abdurahman 1990; Ballal *et al.* 2016; L. Li & Zhang 2026). The experiment was not repeated at other relative humidity levels, as the primary objective of this study was to assess whether live *C. lactis* could serve as a suitable rearing diet for *B. whitei*.

Future research on *B. whitei* should aim to refine the understanding of its biology and rearing requirements. Controlled experiments manipulating temperature and humidity across a wider range would help clarify their effects on number of instars, and fecundity. Additional studies should also investigate the nutritional composition of live versus frozen *C. lactis* to identify key dietary components affecting growth and reproduction. Long-term multigenerational experiments could reveal potential transgenerational effects of diet and environmental conditions on fitness traits. Furthermore, field evaluations of *B. whitei* performance against target pest species under varying crop environments would provide essential data for its practical application as a biological control agent in New Zealand's agricultural systems.

In summary, this study establishes foundational biological information for *B. whitei* and identifies live *C. lactis* as a potential effective and economical rearing diet. The discovery of variable instar numbers and humidity-dependent oviposition reveals previously unreported developmental plasticity within the Anthocoridae. These findings enhance understanding of *B. whitei* biology and provide practical insights for improving mass-rearing protocols for this native predator, thereby supporting its wider use in sustainable biological control programmes in New Zealand.

Acknowledgements

We thank Bioforce Limited for providing the initial populations of *Carpoglyphus lactis* and *Buchananiella whitei*. We thank Dr. Qing-Hai Fan (Ministry for Primary Industries, Plant Health & Environment Laboratory, Auckland) for help in recognising female and male *B. whitei*.

References

Ali M. F., Mashaly A. M. A., Mohammed A. A. & El -Magd Mahmoud Mohammed A. 2011. Effect of temperature and humidity on the biology of *Attagenus fasciatus* (Thunberg) (Coleoptera: Dermestidae). *Journal of Stored Products Research* 47(1): 25–31. https://doi.org/10.1016/j.jspr.2010.07.002

Amin M. R. & Khanjani M. 2024. Development, reproduction and survival *Protogamasellopsis rhizoglyphusi* and *Gaeolaelaps aculeifer* (Mesostigmata: Rhodacaridae, Laelapidae) feeding on two astigmatine mite prey and notes on the behavior of *P. rhizoglyphusi*. *Systematic and Applied Acarology* 29(1): 109–124. https://doi.org/10.11158/saa.29.1.8

Archer T. L., Musick G. L. & Murray R. L. 1980. Influence of temperature and moisture on black cutworm (Lepidoptera: Noctuidae) development and reproduction. *Canadian Entomologist* 112(7): 665–673. https://doi.org/10.4039/Ent112665-7

Baker B. P., Green T. A. & Loker A. J. 2020. Biological control and integrated pest management in organic and conventional systems. *Biological Control* 140: 104095. https://doi.org/10.1016/j.biocontrol.2019.104095

Ballal C. R., Yamada K. & Joshi S. 2016. Morphology and biology of litter-inhabiting *Buchananiella indica* Muraleedharan (Hemiptera:

Anthocoridae). *ENTOMON* 41(1): 11–20.
https://doi.org/10.33307/entomon.v41i1.118

Beretta G. M., Deere J. A., Messelink G. J., Muñoz-Cárdenas K. & Janssen A. 2022. Review: predatory soil mites as biocontrol agents of above- and below-ground plant pests. *Experimental & Applied Acarology* 87(2-3): 143–162.
https://doi.org/10.1007/s10493-022-00723-w

Bonte J., Van de Walle A., Conlong D. & De Clercq P. 2017. Eggs of *Ephestia kuehniella* and *Ceratitis capitata*, and motile stages of the astigmatid mites *Tyrophagus putrescentiae* and *Carpoglyphus lactis* as factitious foods for *Orius* spp. *Insect Science* 24(4): 613–622.

Bonte M. & Clercq P. D. 2010. Impact of artificial rearing systems on the developmental and reproductive fitness of the predatory bug, *Orius laevigatus*. *Journal of Insect Science* 10(1): 104.

Broufas G. D., Pappas M. L. & Koveos D. S. 2009. Effect of relative humidity on longevity, ovarian maturation, and egg production in the olive fruit fly (Diptera: Tephritidae). *Annals of the Entomological Society of America* 102(1): 70–75.
https://doi.org/10.1603/008.102.0107

Cao J., Zhang K., Li X. & Zhang Z. Q. 2025. Individual development and population growth of four phytoseiid predators feeding on *Carpoglyphus lactis* (Acari: Phytoseiidae, Carpoglyphidae). *Systematic and Applied Acarology* 30(8): 1534–1538.
https://doi.org/10.11158/saa.30.8.13

Chen X., Zhang K. & Zhang Z. 2025. Effects of variable mating opportunity, delay, and male mating experience on the lifespan, female reproductive traits, and offspring traits of *Phytoseiulus persimilis* (Acari: Phytoseiidae). *Experimental and Applied Acarology* 94(2): 33.

Chen X. & Stansly P. A. 2014. Biology of *Tamarixia radiata* (Hymenoptera: Eulophidae), parasitoid of the citrus greening disease vector *Diaphorina citri* (Hemiptera: Psylloidea): a mini review. *Florida entomologist* 97(4): 1404–1413.

Deere J. A., Beretta G. M., van Rijn P. C., Messelink G. J., Leman A. & Janssen A. 2024. Does alternative food for predatory arthropods improve biological pest control? A meta-analysis. *Biological Control* 198: 105605.
https://doi.org/10.1016/j.biocontrol.2024.105605

Dhileepan K. 2001. Effectiveness of introduced biocontrol insects on the weed *Parthenium hysterophorus* (Asteraceae) in Australia. *Bulletin of Entomological Research* 91(3): 167–176.

Esperk T., Tammaru T. & Nylin S. 2007. Intraspecific variability in number of larval instars in insects. *Journal of Economic Entomology* 100(3): 627–645.
https://doi.org/10.1603/0022-0493(2007)100[627:ivinol]2.0.co;2

Fadamiro H. Y. & Baker T. C. 1999. Reproductive performance and longevity of female European corn borer, *Ostrinia nubilalis*: effects of multiple mating, delay in mating, and adult feeding. *Journal of Insect Physiology* 45(4): 385–392.

Hamasaki K. & Matsui M. 2006. Development and reproduction of an aphidophagous coccinellid, *Propylea japonica* (Thunberg) (Coleoptera: Coccinellidae), reared on an alternative diet, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs. *Applied Entomology and Zoology* 41(2): 233–237.

He L., Zhao S., Ali A., Ge S. & Wu K. 2021. Ambient humidity affects development, survival, and reproduction of the invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), in China. *Journal of Economic Entomology* 114(3): 1145–1158.
https://doi.org/10.1093/jee/toab056

Herrick N. J., Cloyd R. A., Conner M. A. & Motolai G. 2021. Insidious flower bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), predation on western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), on Transvaal daisy, *Gerbera jamesonii*, cut flowers and chrysanthemum, *Tanacetum×grandiflorum*, plants under laboratory and greenhouse conditions. *Biological Control* 163: 104739.
https://doi.org/10.1016/j.biocontrol.2021.104739

Huynh M. P., Shelby K. S. & Coudron T. A. 2021. Recent advances in insect rearing methodology to promote scientific research and mass production. *Insects* 12(11): 961.

Jaiswal D. K., Gawande S. J., Soumia P. S., Krishna R., Vaishnav A. & Ade A. B. 2022. Biocontrol strategies: an eco-smart tool for integrated pest and diseases management. *BMC microbiology 22*(1): 324.
https://doi.org/10.1186/s12866-022-02744-2

Jalali M. A., Tirry L. & De Clercq P. 2009. Effects of food and temperature on development, fecundity and life-table parameters of *Adalia bipunctata* (Coleoptera: Coccinellidae). *Journal of Applied Entomology* 133(8): 615–625.
https://doi.org/10.1111/j.1439-0418.2009.01408.x

Ji J., Zhang Y., Lin J., Chen X., Sun L. & Saito Y. 2015. Life histories of three predatory mites feeding upon *Carpoglyphus lactis* (Acari, Phytoseiidae; Carpoglyphidae). *Systematic and Applied Acarology* 20(5): 491–496.
https://doi.org/10.11158/saa.20.5.5

Larivière M. & Larochelle A. 2014. Checklist of the New Zealand Heteroptera (Insecta: Hemiptera): an update based on the 2004 to

2013 literature. *Zootaxa* 3755(4): 347–367.
https://doi.org/10.11646/zootaxa.3755.4.2

Lattin J. D. 1999. Bionomics of the Anthocoridae. *Annual Review of Entomology* 44(1): 207–231.

Lenteren J. C. V. & Tommasini M. G. 2003. Mass production, storage, shipment and release of natural enemies. *Quality control and production of biological control agents: theory and testing procedures* (pp. 181–189). CABI Publishing.
https://doi.org/10.1079/9780851996882.0181

Levi-Mourao A., Madeira F., Meseguer R., García A. & Pons X. 2021. Effects of temperature and relative humidity on the embryonic development of *Hypera postica* Gyllenhal (Col.: Curculionidae). *Insects* 12(3): 250.
https://doi.org/10.3390/insects12030250

Li L.J. & Zhang Z.-Q. 2026. Testing biocontrol potential of an indigenous predator against an invasive pest in New Zealand: *Buchananiella whitei* (Hemiptera: Anthocoridae) and the tomato red spider mite *Tetranychus evansi* (Acari: Tetranychidae). *Journal of Insect Biodiversity* 78(1), 13–20.
https://doi.org/10.12976/jib/2026.78.1.5

Li X.T. & Zhang Z.-Q. 2026. Lacewings (*Mallada basalis*) and minute pirate bugs (*Buchananiella whitei*) as potential biocontrol agents of western flower thrips (*Frankliniella occidentalis*) in strawberries: predation on different thrips stages in no-choice and choice tests. *Journal of Insect Biodiversity* 78(1): 37–44.
https://doi.org/10.12976/jib/2026.78.1.7

Liu Z., Zhang K. & Zhang Z. 2024a. Enhancing the efficiency of egg collection of the astigmatid mite *Carpoglyphus lactis* (Acari: Carpoglyphidae) as a diet for predatory mites. *Systematic and Applied Acarology* 29(2): 355–358.
https://doi.org/10.11158/saa.29.2.14

Liu Z., Zhang K. & Zhang Z. 2024b. Unintended consequences: the adverse effects of royal jelly supplementation in the predatory mite *Amblyseius herbicolus* Chant (Acari: Phytoseiidae). *Systematic and Applied Acarology* 29(2): 335–345.
https://doi.org/10.11158/saa.29.2.12

Mbata G. N. 1986. Combined effect of temperature and relative humidity on mating activities and commencement of oviposition in *Plodia interpunctella* (Hubner) (Lepidoptera: Phycitidae). *Insect Science and its Application* 7(5): 623–628.
https://doi.org/10.1017/S1742758400011553

Mohaghegh J. & Amir-Maafi M. 2007. Reproduction of the predatory stinkbug *Andrallus spinidens* (F.) (Heteroptera: Pentatomidae) on live and frozen prey. *Applied Entomology and Zoology* 42(1): 15–20.
https://doi.org/10.1303/aez.2007.15

Naseer M. & Abdurahman U. C. 1990. Reproductive biology and predatory behaviour of the anthocorid bugs (Anthocoridae: Hemiptera) associated with the coconut caterpillar, *Opisina arenosella* (Walker). *Entomon* 15(3-4): 149–158.

Navarro-Campos C., Wäckers F. L. & Pekas A. 2016. Impact of factitious foods and prey on the oviposition of the predatory mites *Gaeolaelaps aculeifer* and *Stratiolaelaps scimitus* (Acari: Laelapidae). *Experimental & Applied Acarology* 70(1): 69–78.
https://doi.org/10.1007/s10493-016-0061-2

Norhisham A. R., Abood F., Rita M. & Hakeem K. R. 2013. Effect of humidity on egg hatchability and reproductive biology of the bamboo borer (*Dinoderus minutus* Fabricius). *SpringerPlus* 2(1): 9.
https://doi.org/10.1186/2193-1801-2-9

Ogawa Y. & Osakabe M. 2008. Development, long-term survival, and the maintenance of fertility in *Neoseiulus californicus* (Acari: Phytoseiidae) reared on an artificial diet. *Experimental & Applied Acarology* 45(3): 123–136.
https://doi.org/10.1007/s10493-008-9189-z

Omkar S. S. & Mishra G. 2010. Multiple matings affect the reproductive performance of the aphidophagous ladybird beetle, *Coelophora saucia* (Coleoptera: Coccinellidae). *European Journal of Entomology* 107: 177–182.

Pai A., Bennett L. & Yan G. 2005. Female multiple mating for fertility assurance in red flour beetles (*Tribolium castaneum*). *Canadian Journal of Zoology* 83(7): 913–919.

Pakyari H., Amir-Maafi M., Moghadamfar Z. & Zalucki M. 2019. Estimating development and temperature thresholds of *Ephestia kuehniella*: toward improving a mass production system. *Bulletin of Entomological Research* 109(4): 435–442.
https://doi.org/10.1017/S0007485318000718

Parra J. R. P. & Coelho Jr A. 2022. Insect rearing techniques for biological control programs, a component of sustainable agriculture in Brazil. *Insects* 13(1): 105.

Prado S., Jandricic S. & Frank S. 2015. Ecological Interactions Affecting the Efficacy of *Aphidius colemani* in Greenhouse Crops. *Insects* 6(2): 538–575.
https://doi.org/10.3390/insects6020538

R Core Team. 2024. R: A language and environment for statistical computing. [computer software]. Vienna: http://www.R-project.org/

Rahman M. A., Sarker S., Ham E., Lee J. & Lim U. T. 2020. Development and fecundity of *Orius minutus* (Hemiptera: Anthocoridae)

and *O. laevigatus* reared on *Tetranychus urticae* (Acari: Tetranychidae). *Journal of Economic Entomology* 113(4): 1735–1740.

Riddick E. W. 2009. Benefits and limitations of factitious prey and artificial diets on life parameters of predatory beetles, bugs, and lacewings: a mini-review. *BioControl* 54(3): 325–339.

Sobhy I. S., Sarhan A. A., Shoukry A. A., El-Kady G. A., Mandour, N. S. & Reitz S. R. 2010. Development, consumption rates and reproductive biology of *Orius albidipennis* reared on various prey. *Biocontrol* 55(6): 753–765.

Song Z., Nguyen D. T., Li D. & De Clercq P. 2019. Continuous rearing of the predatory mite *Neoseiulus californicus* on an artificial diet. *BioControl* 64(2): 125–137.
https://doi.org/10.1007/s10526-019-09923-7

Tung N. D., Anh N. T. & Fang X. 2022. Effects of factitious prey on the biology and growth rate of the predatory mites *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae). *Zoosymposia* 22: 121.
https://doi.org/10.11646/zoosymposia.22.1.73

Van Lenteren J. C. 2012. The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. *BioControl* 57(1): 1–20.
https://doi.org/10.1007/s10526-011-9395-1

Wang J., Zhang K., Li L. & Zhang Z. 2024. Development and reproduction of four predatory mites (Parasitiformes: Phytoseiidae) feeding on the spider mites *Tetranychus evansi* and *T. urticae* (Trombidiformes: Tetranychidae) and the dried fruit mite *Carpoglyphus lactis* (Sarcoptiformes: Carpoglyphidae). *Systematic and Applied Acarology* 29(2): 269–284.
https://doi.org/10.11158/saa.29.2.7

Wei Y. J. 2010. Variation in the number of nymphal instars in *Nysius huttoni* White (Hemiptera: Lygaeidae). *New Zealand Journal of Zoology* 37(4): 285–296.
https://doi.org/10.1080/03014223.2010.513396

Wickham, H. 2016. *ggplot2: elegant graphics for data analysis* (2nd ed ed.). Springer International Publishing. 10.1007/978-3-319-24277-4

Workman P. J. & Martin N. A. 2002. Towards integrated pest management of *Thrips tabaci* in onions. *New Zealand Plant Protection* 55: 188–192.
https://doi.org/10.30843/nzpp.2002.55.3992

Xu Y., Zhang K. & Zhang Z. 2023. Development, survival, and reproduction of *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) feeding on fresh versus frozen eggs of *Tetranychus urticae* Koch (Acari: Tetranychidae). *Acarologia* 63(1): 24–30.
https://doi.org/10.24349/17km-oc7u

Yan H., Zhang B. & Li Z. P. 2022. Phenotypic plasticity of predatory mite *Amblyseius orientalis* in response to diet switch. *Systematic and Applied Acarology* 27 (6): 1098–1108.
https://doi.org/10.11158/saa.27.6.9

Yanık E. 2011. The effects of different temperatures and relative humidity on the nymphal development, mortality and prey consumption of *Anthocoris nemoralis* (F.) (Heteroptera: Anthocoridae). *Selcuk Journal of Agriculture and Food Sciences* 25(4): 21–26.

Zhang K., Zhang Q. & Zhang Z. 2025. Fresh and frozen dried fruit mites (*Carpoglyphus lactis*) supported the rearing of a predatory mite *Phytoseius leaki* (Acari: Phytoseiidae) with specialised niche requirements. *Journal of Stored Products Research* 112: 102651.
https://doi.org/10.1016/j.jspr.2025.102651

Zhang K. & Zhang Z. 2021. The dried fruit mite *Carpoglyphus lactis* (Acari: Carpoglyphidae) is a suitable alternative prey for *Amblyseius herbicolus* (Acari: Phytoseiidae). *Systematic and Applied Acarology* 26(11): 2167–2176.
https://doi.org/10.11158/saa.26.11.15

Zhang Q., Zhang K. & Zhang Z. 2025. Leaf trichome density influences oviposition preference in *Phytoseius leaki* Schicha (Acari: Phytoseiidae). *Systematic and Applied Acarology* 30(4): 826–830.
https://doi.org/10.11158/saa.30.4.13

Zhu R., Guo J., Yi T., Hou F. & Jin D. 2023. Potential of a winterschmidtiid prey mite for the production of the predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae). *Experimental & Applied Acarology* 91(4): 571–584.
https://doi.org/10.1007/s10493-023-00860-w