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Prey consumption and conversion efficiency in females of two feral populations of *Macrolophus pygmaeus*, a biocontrol agent of *Tuta absoluta*

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Abstract *Macrolophus pygmaeus* (Rambur, 1839) (Hemiptera: Miridae) is a polyphagous predator used in programs of biological control and integrated pest management as a natural enemy against small arthropod pests including whiteflies, thrips, spider mites and aphid. This mirid is also successfully mass reared under factitious prey for commercial purposes. In the present study we assessed and compared the prey consumption, weight gain and conversion efficiency in females of two populations of *M. pygmaeus*, from mainland Portugal and the Azores, fed on single prey diets of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs, or *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) eggs. We found that female's prey consumption on eggs of *T. absoluta* was higher than that of *E. kuehniella*, presumably due to the comparative size/amount of biomass of the eggs. Translating prey consumption in biomass ingested, we only found a significant difference for consumption on *E. kuehniella* eggs by *M. pygmaeus* from the Azores. Despite the smaller size of females from the Azores, they were able to consume more prey and ultimately reaching a similar body weight and conversion efficiency compared with females from mainland, independently of the prey provided. Our results are in line with a previous study, showing differences in the life-history traits of *M. pygmaeus* from mainland Portugal and Azorean populations fed

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on alternative prey. From an applied perspective, our results are a contribution to the decision-making on the use of the most effective biocontrol agents for different prey and/or agroecosystem contexts.

Keywords Biological control · Predators · Miridae · Biological traits · Egg-prey · *Ephestia kuehniella*

Introduction

The South American leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) was firstly reported outside its native range in Eastern Spain in 2006 and, in 2007, dispersed to Africa via Algeria, Morocco and Tunisia (Desneux et al., 2011, 2022). Now, it is widely distributed in more than 100 countries (EPPO, 2023). It was firstly referred to the Azores, in 2012 (Vieira, 2016), but no information is available on the origin and date of colonization. Most likely, the Azorean populations have originated from mainland Portugal. The primary host of this pest seems to be *Solanum lycopersicum* L., although it can feed and develop on other plants within Solanaceae and Convolvulaceae, such as the bittersweet nightshade (*Solanum dulcamara* L.), black nightshade (*Solanum nigrum* L.), cape gooseberry (*Physalis peruviana* L.), common thorn (*Datura stramonium* L.), eggplant (*Solanum melongena* L.), pepper (*Capsicum annuum* L.), potato (*Solanum tuberosum* L.), sweet potato (*Ipomea batatas* (L.) Lam.), tobacco (*Nicotiana tabacum* L.) and wild tomato (*Lycopersicon hirsutum* Dunal) (Vieira, 2016). *Tuta absoluta* is a key pest of tomato crops, causing devastating economic impacts to growers (Biondi et al., 2018), sometimes reaching 100% of economic losses (Rostami et al., 2020). Foliage damage is the primary cause of economic losses, especially when populations are abundant. The larvae feed on leaf tissues producing mines that can destroy the leaves when infestations are high. The reduction of leaf tissues induces dispersion to the fruits. The larvae penetrate fruits, often below the calyx, facilitating fruit infection by pathogens (Chermiti et al., 2009; Balzan & Moonen, 2012; Guedes & Picanço, 2012). Just after its detection in the Azores, the management of *T. absoluta* populations was mainly based on chemical control (Oliveira et al., 2023). Over the last 5 years, additional biotechnical control strategies have been used into horticultural farms, namely water traps with pheromones and yellow sticky traps (Information provided by the Agricultural Services of the Azores). The legal regime for the conservation of nature and biodiversity at the Azores according to the Regional Legislative Decree (DLR no. 15/2012/A, of April 2) limits the introduction of exotic natural enemies and recommends the use of native biological agents.

The zoophytophagous mirid *Macrolophus pygmaeus* (Rambur) (Hemiptera: Miridae) is recognized as one of the most promising biological control agents against *T. absoluta* (Arnó et al., 2021). This mirid bug has been successfully mass reared for commercial purposes (van Lenteren, 2012) and used in the biological control of different arthropod pests, such as, aphids, thrips, whiteflies, and spider mites (Fauvel et al., 1987; Alvarado et al., 1997; Barnadas et al., 1998; Riudavets & Castañé, 1998; Margaritopoulos et al., 2003; Perdikis et al., 2008; Arnó et al., 2009; Calvo et al., 2009; Urbaneja et al., 2009; Castañé et al., 2011; Urbaneja et al., 2012). Although Dicyphini mirids are zoophytophagous, the level of damage they can cause to host plants is variable, depending on the species. *Macrolophus pygmaeus* has been seen as a candidate to replace *Nesidiocoris tenuis* (Reuter), in biological control in tomato crops, because the damage inflicted on plants is much less (Arnó et al., 2010; Castañé et al., 2011). In addition, plant feeding allows mirids being present in the field, when prey is scarce, which is advantageous for biological control (Abraços-Duarte et al., 2021; Pérez-Hedo et al., 2021; Coppel & Mertins, 1977).

Augmentative biological control is a widely used strategy to obtain an immediate control of pests in crops with a short production cycle or for control of pests during several generations in crops with a long production cycle. This strategy involves large-scale regular releases of mass-produced natural enemies, being a sound alternative to control pest populations in a wide range of crop systems (van Lenteren et al., 2018). Despite being one of the most destructive cosmopolitan pests of stored grains, particularly flour, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs are a suitable substitute prey for mass rearing of a wide range of predator and parasitoid species to be used in augmentative biological control (Mamay et al., 2022). However, due to different nutritional quality in relation to natural prey, their use can alter traits of natural enemies, thus limiting mass production under controlled conditions (Awmack & Leather, 2002). Biological and ecological traits of pests and their natural enemies should be studied in order to predict how successful a biocontrol agent will be during augmentative biological control (Coppel & Mertins, 1977). Pest population suppression is largely determined by the relationship between the ability of the biocontrol agent to consume prey and pest population growth (Coppel & Mertins, 1977). Females are, in general, the most voracious developmental stage and, depending on the availability of prey, biomass consumption may translate in a positive reproductive numerical response. That is, changes in the number of predators on prey colonies may result from two different mechanisms: attraction of predators to prey aggregations (aggregational response) and increased rate of predator reproduction when prey is abundant (reproductive numerical response). Predation or parasitism rate must be higher than the growth rate of prey/host (Coppel & Mertins, 1977). In insect pests with fast population growth, such as aphids, it is essential that biocontrol agents have a high prey consumption (Borges et al., 2011, 2013). However, prey may differ in their suitability driving alterations on predator's survival and development rate. The consumption of different prey species can have consequences for the predator's reproductive numerical responses changing, by this way, the success of biological control. Predator egg production also requires nutritional intake beyond a maintenance level, and thus high-quality food sources are mandatory for supporting predator reproduction (Seagraves, 2009; Sebastião et al., 2015; Hodek, 1962; Hodek & Honek, 1996; Hodek & Evans, 2012).

Recently, Borges et al. (2023) provided experimental evidence that *T. absoluta* eggs are an essential prey for *M. pygmaeus*. That is, when fed only with *T. absoluta* eggs, nymphs of *M. pygmaeus* can complete development and the originated adults are able to reproduce. From an applied point of view, the assessment of the number of eaten (killed) eggs of *T. absoluta* is an important predictor of a predator's potential as a biological control agent. Prey consumed by insects can vary greatly in quality. Prey quality affects growth, development and reproduction. The percentage of consumed prey biomass converted into predator biomass (the so-called efficiency of conversion of ingested material or relative growth rate) is a useful proxy to test food quality (Waldbauer, 1968). Expressing prey consumption as the amount of biomass intake, allows i) to compare similar biological traits among different prey, given that species do not have the same body weight and ii) to estimate some physiological parameters, as the conversion efficiency. Following biomass consumption, weight increases and conversion efficiency are good predictors of energy intake and associated costs (Odum, 1956; Waldbauer, 1968). According to the universal model of energy flow (Odum, 1956), conversion efficiency corresponds to the proportion of biomass consumed allocated to growth.

In the present study, we assessed the prey consumption, the weight gain and conversion efficiency of *M. pygmaeus* females when fed on *T. absoluta* eggs. We compared two field collected populations of *M. pygmaeus*, i.e., one from mainland Portugal and one from the Azores archipelago. The aim of our study was to understand the predatory activity of *M. pygmaeus*, including that of the native population of the Azores, assessing to what extent it will be possible to mass-rear under laboratory conditions, using as factitious prey, *T. absoluta* eggs, as well as investigating if prey consumption may vary among populations of different geographical origin.

Materials and methods

Biological materials

Specimens of *M. pygmaeus* were obtained from two field populations of different geographical origin: 1) Mainland Portugal population, specimens originated from the Oeste region of Portugal (Azueira, Mafra: 39°00′43.8″ N 9°16′49.1″ W; Silveira, Torres Vedras: 39°07′02.5″ N 9°21′54.1″ W; Tapada da Ajuda, Lisbon: 38°42′45.8″ N 9°11′02.8″ W), collected both in greenhouse and open field crops, and maintained in laboratory conditions during several generations; 2) Azorean population, based on specimens collected in S. Miguel Island, on *S. lycopersicum* plants, in five different locations (Pico da Pedra: 37°47′48.1″ N 25°35′51.7″ W; Lagoa: 37°45′4.3″ N 25°34′27.2″ W; Ribeira Grande: 37°48′49.59″ N 25°31′41.10″ W; two locations on Arrifes: 37°45′1.54″ N 25°41′28.70″ W; 37°45′1.54″ N 25°41′28.70″ W). Laboratory populations were maintained, separately, in rearing net cages (40×40×40 cm). The experiments with *M.*

pygmaeus collected in the Azores were performed shortly after its collection in the field, not remaining for more than 2 to 3 generations under laboratory conditions. For mainland populations maintained in laboratory conditions during several generations, monthly refreshments were made.

One potted tomato plant, as well as *E. kuehniella* eggs, provided as a source of protein, were offered twice a week to the mirids within the cages. The eggs of, E. *kuehniella* was used as a reference diet. *Ephestia kuehniella* is an important pest of stored products (Cox & Bell, 1991; Hill, 2006) and its eggs have been commonly used to mass-rear different biocontrol agents (Hamasaki & Matsui, 2006; Vandekerkhove & De Clercq, 2010; Moghaddassi et al., 2019; Gallego et al., 2022). Additionally, the mirids were fed on honey droplets (50% in water) placed over the leaflets. Tomato plant was substituted by a fresh one, every two days. The mirids were reared at 25 ± 1 °C, 75 ± 5% relative humidity and 16 L:8D light regime.

Ephestia kuehniella eggs were provided by CBA (Centre of Biotechnology of the Azores), where the lepidopteran is mass reared. *Tuta absoluta* was collected in a greenhouse in S. Miguel Island and used to start a small-scale mass rearing program in the laboratory, as described in Borges et al. (2023).

Prey consumption

Several rearing cages were made to obtain enough nymphs of the mirid populations for the experiments. Approximately, 50 *M. pygmaeus* adults from the stock population were placed in a rearing cage, and *E. kuehniella* eggs and honey diluted in water were provided over a tomato leaf placed in a water container. These procedures were the same for both mirid populations. After 10-days exposure, all adult mirids were removed and each cage was kept for nymphal development. Twice a week, fresh *E. kuehniella* eggs were provided, as well as honey diluted in water. Recently emerged adults were picked up every two days and transferred to a separate rearing cage, until reaching 9 to 12 days old. At that time, females were collected to be used in the prey consumption tests. The sex of adult specimens was identified based upon the abdomen shape: rounded, thick, and symmetric, ventrally with a central groove for females; and thin, asymmetric, without groove and tapered near the end for males.

Twenty-four hours prior to testing, females were fed only with a tomato plant and a droplet of honey diluted in water. For the prey consumption test, 50 eggs of *E. kuehniella* or 80 eggs of *T. absoluta* were offered over a tomato leaflet to a single predator female in an acrylic box (3 cm diameter × 2 cm height), for 24 hours. The weight of the eggs of *E. kuehniella*, *T. absoluta* and females of *M. pygmaeus* were recorded before and after the 24 hour-test, using Sartorius ultra-microbalance. Female prey consumption was expressed in terms of the number of prey eggs and the amount of biomass ingested. Weight gain by females of *M. pygmaeus* expresses the difference of the body weight assessed before and after the 24 hour-test and the percentage of biomass ingested was calculated by balancing the difference in the weight loss of the eggs, relative to the initial weight. Biomass ingested (BI), relative growth rate (RGR), and conversion efficiency (CE) by females were calculated according to the formulas (Soares et al., 2004):

$$\mathrm{BI(mg)} = \mathrm{EWi} – \mathrm{EWf}$$

$$\mathrm{RGR\%} = \frac{\mathrm{PWf} - \mathrm{PWi}}{\mathrm{PWi}} \times 100$$

$$\mathrm{CE\%} = \frac{\mathrm{PWf} - \mathrm{PWi}}{\mathrm{BI}} \times 100$$

where, EWi and EWf are the initial and final weight of the eggs, and PWi and PWf are the initial and final weights of the predator. The experiment was conducted with 10 replicates.

Statistical analysis

For statistical analysis, the following independent variables were considered: i) prey species (*T. absoluta* or *E. kuehniella* eggs); and ii) origin of population (Azores or Portugal mainland). Generalized Linear Models (GZLM) were used to test statistical significance of the biological parameters for prey, regions and interactions between independent factors. Data were firstly examined for normal distribution, using the Kolmogorov-Smirnov test. When the previous condition of normality was not verified, the data were log-transformed. If normal distribution was confirmed, GZLM analyses considered the normal error distribution and the identity link function. If not, Poisson error distribution and the Log link function were applied. Pairwise multi-comparisons were carried out and P values corrected using Bonferroni test.

Mean values were considered significantly different when P < 0.05. SPSS v. 27 was used to perform the statistical analyses (IBM Corp 2020).

Results

Initial weight of the eggs

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and the population origin of *M. pygmaeus* (Azores or Portugal mainland) in relation to the initial weight of the eggs provided to *M. pygmaeus* females (Chi-Square = 2.926, df = 1, *P* = 0.087; Table 1). The eggs of *E. kuehniella* (1.32 ± 0.01 mg) were significantly heavier than those of *T. absoluta* (0.83 ± 0.01 mg) (Chi-Square = 1516.76, df = 1, P ≤ 0.0001) and the eggs provided to *M. pygmaeus* females of mainland population was significantly heavier (1.10 ± 0.01 mg) than those provided to Azorean females (1.05 ± 0.01 mg) (Chi-Square = 14.89, df = 1, *P* = 0.001).

Final weight of the eggs

A significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and the population origin of *M. pygmaeus* (Azores or Portugal mainland) in relation to the final weight of the eggs (mg) provided to *M. pygmaeus* females (Chi-Square = 11.84, df = 1, *P* = 0.001; Table 1). We only found a significant difference for the final weight of *E. kuehniella* after being consumed by *M. pygmaeus* females from mainland Portugal, that is, the final weight of the eggs was significant higher (Table 1).

Prey consumption

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and population origin of *M. pygmaeus* (Azores or Portugal mainland) with respect to the prey consumption of *M. pygmaeus* females (Chi-Square = 3.456, df = 1, *P* = 0.063). The females of *M. pygmaeus* consumed a significantly higher number of eggs of *T. absoluta* (40.70 ± 4.56) in comparison to *E. kuehniella* (26.00 ± 3.56) (Chi-Square = 9.018, df = 1, *P* = 0.003). Females of *M. pygmaeus* from the Azores population were significantly more voracious (42.70 ± 3.53 eggs consumed) compared to *M. pygmaeus* from mainland Portugal (24.00 ± 4.48 eggs consumed) (Chi-Square = 14.593, df = 1, P < 0.001) (Table 1).

Amount of biomass ingested

We found a significant interaction between prey species (*T. absoluta* or *E. kuehniella* eggs) and population origin of *M. pygmaeus* (Azores or mainland Portugal) (Chi-Square = 13.74, df = 1, *P* = 0.001). A significant difference between populations of *M. pygmaeus* on the amount of ingested mass was observed in the case of *E. kuehniella* eggs only, with a higher performance shown by *M. pygmaeus* females from the Azores (Table 1).

Table 1 Ponderal characteristics (mean ± SE) of *T. absoluta* or *E. kuehniella* eggs before and after consumption, prey consumption (number of eggs consumed per 24 h ± SE), and the amount of biomass ingested (mean ± SE) by *M. pygmaeus* females from the Azores or Portugal mainland populations fed on single diets of *E. kuehniella* or *T. absoluta*. Different letters in the same row mean significant differences (*GZLM, p < 0.05)

	Azorean population		Portugal mainland population	
	T. absoluta	*E. kuehniella*	*T. absoluta*	*E. kuehniella*
Initial weight of the eggs (mg)	0.80 ± 0.01	1.33 ± 0.01	0.87 ± 0.01	1.34 ± 0.02
Final weight of the eggs (mg)	0.37 ± 0.06a*	0.42 ± 0.05a	0.52 ± 0.07a	1.00 ± 0.07b
Prey consumption (number of eggs)	45.50 ± 6.57	39.90 ± 1.87	35.90 ± 6.42	12.10 ± 2.97
Biomass ingested (mg)	0.43 ± 0.07a*	0.89 ± 0.04b	0.35 ± 0.07a	0.34 ± 0.08a
Biomass ingested (%)	0.54 ± 0.08bc*	0.68 ± 0.03c	0.41 ± 0.08ab	0.25 ± 0.06a

Percentage of biomass ingested

A significant interaction was found between the prey species (*T. absoluta* or *E. kuehniella* eggs) and the population origin of *M. pygmaeus* (Azores or Portugal mainland) (Chi-Square = 5.374, df = 1, $P = 0.02$; Table 1). The *M. pygmaeus* females from the Azores ingested a higher rate of biomass from eggs of *E. kuehniella* in comparison to those from mainland.

Initial body weight of *M. pygmaeus* females

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and the population origin of *M. pygmaeus* (Azores or mainland Portugal) on the initial body weight of *M. pygmaeus* females (Chi-Square = 3.219, df = 1, $P = 0.073$; Table 2). Initial body weight of *M. pygmaeus* females fed with *T. absoluta* eggs (1.16 ± 0.04 mg) did not significantly differ from that of females fed with *E. kuehniella* eggs (1.16 ± 0.03 mg) (Chi-Square = 0.008, df = 1, $P = 0.928$). Initial body weight of *M. pygmaeus* females from the mainland (1.24 ± 0.03 mg) was significantly higher that of the females from Azores (1.09 ± 0.03) (Chi-Square = 18.153, df = 1, P < 0.001).

Final body weight of *M. pygmaeus* females

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and population origin of *M. pygmaeus* (Azores or Portugal mainland) on the final body weight of *M. pygmaeus* females (Chi-Square = 3.721, df = 1, $P = 0.0543$; Table 2). Final body weight of *M. pygmaeus* females fed with *T. absoluta* eggs (1.26 ± 0.04 mg) did not significantly differ from that of females provided with *E. kuehniella* eggs (1.33 ± 0.04 mg) (Chi-Square = 2.173, df = 1, $P = 0.140$). Final body weight of females of *M. pygmaeus* from the mainland (1.32 ± 0.03 mg) did not differ from that of the females of the Azores (1.27 ± 0.04 mg) (Chi-Square = 0.998, df = 1, $P = 0.318$) (Table 2).

Weight gain

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and the population origin of *M. pygmaeus* (Azores or Portugal mainland) on the weight gain of *M. pygmaeus* females (Chi-Square = 0.567, df = 1, $P = 0.451$; Table 2). Weight gain *M. pygmaeus* females fed with *E. kuehniella* eggs (0.17 ± 0.03 mg) was significantly higher than that of females fed with *T. absoluta* eggs (0.09 ± 0.04 mg) (Chi-Square = 3.894, df = 1, $P = 0.048$). Weight gain of Azorean *M. pygmaeus* females (0.18 ± 0.03 mg) was significantly higher than that of females from mainland (0.08 ± 0.03 mg) (Chi-Square = 78.293, df = 1, $P = 0.007$).

Relative growth rate

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and the population origin of *M. pygmaeus* (Azores or Portugal mainland) on the relative growth rate of *M. pygmaeus* females (Chi-Square = 0.497, df = 1, $P = 0.481$; Table 2). Relative growth of *M. pygmaeus* females fed with *E. kuehniella* eggs (14.90 ± 2.98%) was significantly higher than that of females fed with *T. absoluta* eggs (0.09 ± 0.04%) (Chi-Square = 8.593, df = 1, $P = 0.003$). Relative growth rate of Azorean *M. pygmaeus* females (16.80 ± 3.00 mg) did not significantly differ of females from mainland (6.64 ± 2.04%) (Chi-Square = 3.374, df = 1, $P = 0.066$).

Table 2 Ponderal characteristics (mean ± SE), relative growth rate (mean ± SE) and conversion efficiency (% ± SE) of *M. pygmaeus* females from the Azores or Portugal mainland populations fed on single diets of *E. kuehniella* or *T. absoluta*

	Azorean population		Portugal mainland population	
	T. absoluta	*E. kuehniella*	*T. absoluta*	*E. kuehniella*
Initial weight of *M. pygmaeus* (mg)	1.05 ± 0.03	1.12 ± 0.04	1.28 ± 0.004	1.21 ± 0.03
Final weight of *M. pygmaeus* (mg)	1.18 ± 0.05	1.35 ± 0.06	1.33 ± 0.05	1.31 ± 0.04
Weight gain (mg)	0.13 ± 0.04	0.24 ± 0.05	0.05 ± 0.04	0.10 ± 0.03
Relative growth rate (%)	12.39 ± 3.65	21.21 ± 4.51	4.67 ± 2.91	8.59 ± 2.71
Conversion efficiency (%)	0.31 ± 0.08	0.26 ± 0.05	0.03 ± 0.10	0.25 ± 0.10

Conversion efficiency

No significant interaction was found between prey species (*T. absoluta* or *E. kuehniella* eggs) and population origin of *M. pygmaeus* (Azores or Portugal mainland) on the conversion efficiency of *M. pygmaeus* females (Chi-Square = 2.513, df = 1, $P = 0.113$; Table 2). Conversion efficiency of *M. pygmaeus* females fed with *E. kuehniella* eggs (0.25 ± 0.06) did not significantly differ from that of females fed with *T. absoluta* eggs (0.17 ± 0.07) (Chi-Square = 0.990, df = 1, $P = 0.320$). No significant differences were observed between *M. pygmaeus* females from the Azores (0.28 ± 0.04) and those from mainland (0.14 ± 0.08) (Chi-Square = 2. 923, df = 1, $P = 0.087$) for the same variable.

Discussion

We assessed and compared the number of eggs of *E. kuehniella* or *T. absoluta* consumed by females of *M. pygmaeus* from populations of two different geographical origins. We found that the number of eggs of *T. absoluta* consumed by *M. pygmaeus* females was higher than that of *E. kuehniella*. This maybe related with the relative amount of biomass of the two prey-species eggs. The eggs of *T. absoluta* are very small, even compared with other Lepidopteran species (0.36 mm long and 0.22 mm in diameter (EPPO, 2005)). In our study, the weight of *E. kuehniella* eggs was 1.59 times higher than that of *T. absoluta* eggs (1.32 vs 0.83, respectively). Using the same comparative relationship, the prey consumption of *M. pygmaeus* females on *T. absoluta* eggs was 1.56 higher than on *E. kuehniella* eggs.

We also found that the eggs provided to *M. pygmaeus* females of mainland population was significantly heavier (1.10 ± 0.01 mg) than those provided to Azorean females (1.05 ± 0.01 mg). Despite that statistical difference, this represents a residual difference of 4% in egg.

The number of *T. absoluta* eggs consumed in 24 h by *M. pygmaeus* females (40.70 ± 4.56) is within the range of values reported by previous studies. Urbaneja et al. (2009), reported that when females were provided with 60 eggs of *T. absoluta*, they were able to consume in 24 h all the eggs. Chailleux et al. (2013), for an experimental period of 12 h, recorded a mean value of about 10 eggs of *T. absoluta*. In a more recent study, the daily prey consumption of *M. pygmaeus* females was 60.7 ± 5.3 eggs of *T. absoluta* (author's personal observations).

Our results suggest a higher performance of the females from the Azorean population of *M. pygmaeus* in comparison to those of mainland population. In fact, we found that *M. pygmaeus* females from the Azores consumed about 78% more eggs of both preys than those from mainland (42.7 vs 24.0 eggs). In respect to the biomass ingested, the Azorean females also showed a higher performance, with about 54% to 68% of the prey egg biomass ingested, in comparison with 25% to 41%, in the case of mainland females. Nevertheless, no differences were observed between the two populations in relation to the relative growth rate and conversion efficiency.

These results are in line with Borges et al. (2023), which was aimed at contrasting life-history variables of two field populations of *M. pygmaeus* (Azores vs Portugal mainland) under two alternative prey (*T. absoluta* vs *E. kuehniella* eggs). Data revealed that variables with direct impact on fitness, such as lifetime fertility, give a better performance to the Azorean population of the predator. Azorean *M. pygmaeus* females were bigger in size, matured earlier and had a higher reproduction rate for longer periods than those of the mainland population. Genetic structure differs between field populations of *M. pygmaeus*, as well as between naturally occurring or mass-reared ones (Sanchez et al., 2012; Streito et al., 2017). Evolutionary context may have caused variation in the genetic structure in several populations of Mediterranean region. For example, during glaciations, populations geographically isolated by ice fields or permafrost that covered northern and center of Europe (Hewitt, 2000) might have evolved independently and become genetically differentiated (Sanchez et al., 2012). In the previous study (Borges et al., 2023) we found that the origin can affect the initial body weight of mirid. However, in the present study, we found no differences in the initial body weight between the two studied populations of *M. pygmaeus*, reared with the same diet, i.e., *E. kuehniella*.

In the present study, we also assessed the effect of population origin (Azores vs mainland Portugal) and prey diets (*T. absoluta* vs *E. kuehniella* eggs) on the weight gain and conversion efficiency of *M. pygmaeus* females. We found that the weight gain of *M. pygmaeus* females was similar in both tested diets, i.e., *T. absoluta* eggs and *E. kuehniella* eggs, but differed between the two studied populations of *M. pygmaeus*, with the Azorean females showing higher values than mainland females. Analyzing some results obtained in this study, it comes evident that, in general, females from the Azores were able to consume more prey (Azores: 42.70 ± 3.53 eggs consumed vs mainland: 24.00 ± 4.48 eggs consumed) and ultimately reaching a similar body weight comparing with females from mainland (mainland: 1.32 ± 0.03 mg vs Azores: 1.27 ± 0.04 mg), independently of the prey provided. Considering the general model of biomass/energy flow (Odum, 1956), we estimated that about 3.9% to 20.5% of egg-prey biomass ingested is converted to body biomass by *M. pygmaeus* females, corresponding to a relative growth rate between 3 to 31%, depending on prey species and population origin of the predator. Our results provide new information on how *M. pygmaeus* may perform under different prey resources and what are the physiological consequences in terms of each of the resource used for growth and basal metabolism maintenance. As far as we know, our study is the first aiming to access conversion efficiency of *M. pygmaeus* females. A previous study on *Lygus hesperus* Knight (Miridae) reported that females ingested in 24 hours an amount of prey corresponding to 169% of their body weight, while males ingested only 98% (Strong & Landes, 1965). A study on consumption requirements of the mirid predator *Blepharidopterus angulus* (Fallen) (Miridae) of *Eucallipterus tiliae* L., aphids under low temperatures (14 °C), reported that the efficiency in the transformation of the weight of aphids absorbed into the weight of the body of the predator decreases from the 3rd larval stage (from 46% for the 1st stage to 19% in adult females) (Glen, 1973). Body weight of Azorean females were similar to females of *M. pygmaeus* reared for 30 generations either on tobacco leaves and fed on eggs of *E. kuehniella* and without plants (1.36 ± 0.03) (Vandekerkhove et al., 2011).

From an applied point of view, our study provides information on prey consumption of *T. absoluta* by adult females of *M. pygmaeus* and new insights on how its predation performance may vary among populations. With regard to these traits, some differences were significant, including differences between females of the two populations. *Tuta absoluta* and *E. kuehniella* were readily consumed by *M. pygmaeus*. In terms of the number of eggs consumed, females of the Azores were more voracious against *T. absoluta* but, when prey consumption was expressed in the amount of biomass ingested, females from mainland were more voracious against *E. kuehniella*. The consumption of *E. kuehniella* translates in a higher weight gain and relative growth rate and Azorean female gain more weigh independently of the prey, but conversion was marginally not significant. Despite the observed differences in some biological traits, the results of this study provide evidence of the suitability of using *E. kueniella* eggs as factitious prey to mass-rear *M. pygmaeus*, under laboratory conditions. Further studies on the nymphal performance of the predator (Perdikis et al., 1999; Lykouressis et al., 2009) are needed for a more complete idea about the potential of *M. pygmaeus* as a biological control agent of *T. absoluta*. Finally, gathering data on the biology and ecology of biocontrol agents feeding on different prey species are vital to implemented sustainable pest management programs of *T. absoluta* in Portugal. In this context, a recent study shows the economic and financial commercial viability of a continuous mass production of *M. pygmaeus* to implement an augmentative biological control approach (Dutra et al., 2023).

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Declarations

Competing interests The authors have no financial or non-financial conflict interests to disclose.

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