Biological parameters and fertility life table of *Aphis forbesi* Weed, 1889 (Hemiptera: Aphididae) on strawberry

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Abstract

This study provides the first contribution of the biology and life table of *Aphis forbesi* Weed, 1889 (Hemiptera: Aphididae), an important strawberry pest throughout the world. This species lives in the crown and leaf petioles of the plant. It is difficulty to rear this species in laboratory due to protocooperation with ants observed only in the field. We studied the life cycle of *A. forbesi* on the leaves of the Albion strawberry cultivar at 25 ± 2 °C, 60 ± 10% relative humidity, and a 12-h photophase. The experiment was randomised with 100 replicates. The parameters of the fertility life table were calculated using *TabVida*. In the population studied, 25% and 46% had four and three instars, respectively. A mean of 1.43 nymphs per female per day was generated. The mean reproductive period was seven days and the mean longevity was 10 days. In every 11 days there is a generation of *A. forbesi*, where each female has the potential to generate between 6 to 9 individuals daily, increasing its population by 1.2 times. The average life cycle was 16.8 days. High viability observed in all instars and the resulting values of R_0, r_m and λ suggest that *A. forbesi* has the capacity to increase their numbers in a short period of time, while generating high populations in strawberry crops, requiring differential management.

Keywords: Fragaria x *ananassa*, root aphid, biological cycle, fertility life table.

Parâmetros biológicos e tabela de vida de fertilidade de *Aphis forbesi* Weed, 1889 (Hemiptera: Aphididae) em morangueiro

Resumo

Este trabalho apresenta a primeira contribuição ao estudo de biologia e tabela de vida de fertilidade de *Aphis forbesi*, Weed, 1889 (Hemiptera: Aphididae), uma importante praga de morangueiro no mundo. Esta espécie se desenvolve na coroa e pecíolo do morangueiro. O desenvolvimento desta espécie em laboratório apresentou dificuldades, possivelmente devido à protocooperação com formigas, observada em campo durante coletas. O ciclo de vida de *A. forbesi* foi estudado em folhas de morangueiro cultivar 'Albion' a 25 ± 2 °C, 60 ± 10% umidade relativa, e fotofase de 12 horas. O experimento foi inteiramente casualizado com 100 repetições. Os parâmetros da tabela de vida de fertilidade foram calculados usando o software *TabVida*. Na população estudada observou-se que as ninfas apresentaram três e quatro instares, sendo 46 e 25% respectivamente, dos indivíduos que completaram o ciclo de vida. Foi gerada uma média de 1,43 ninfas/ fêmea/ dia. O período reprodutivo médio foi de 7 dias e a longevidade média 10 dias. A cada 11 dias ocorre uma geração de *A. forbesi* onde cada fêmea tem capacidade de gerar de 6 a 9 indivíduos aumentando em 1,2 vezes a população. O ciclo de vida de *A. forbesi* durou em média 16,8 dias. A alta viabilidade observada em todos os estádios, e os valores de R_0, r_m e λ sugerem que *A. forbesi* tem a capacidade de aumentar seu número em um curto período de tempo, gerando altas populações no cultivo do morangueiro, exigindo manejo diferenciado.

Palavras-chave: Fragaria x *ananassa*, pulgão-da-raiz, ciclo biológico, tabela de vida e fertilidade.

1. Introduction

The *Aphis forbesi* Weed, commonly known as the root aphid is native to North America (Blackman and Eastop, 2006), it is an aphid pest affecting strawberry crops (Passos et al., 2000; Cédola and Greco, 2010; Araujo et al., 2013; Bernardi et al., 2013; Zawadneak et al., 2014). *A. forbesi* is also reported as a vector of the strawberry crinkle virus (Babovic and Krczal, 1976). This aphid species is easily recognised because it forms colonies in the crown and petioles of strawberry plants (Bernardi et al., 2013; Zawadneak et al., 2014). It can also be associated with ants (*Solenopsis* sp. and *Camponotus* sp.) that spread the pests in the fields and protect their colonies with mounds of soil, making its control more difficult (Zawadneak et al., 2014).

Fertility life tables aid in understanding the population dynamics of a given species (Van Lenteren and Woets, 1988; Bellows Junior et al., 1992). The reasons underlying the growth of species that are considered pests are important factors in pest management because they help predicting future increases in a population (Guldemond et al., 1998). In the context, information from fertility life tables can aid in the applied biological control programmes by assessing the reproductive potential of pests and their natural enemies (Bellows Junior et al., 1992; Bernardi et al., 2013).

Although the root aphid is present in strawberry-producing regions, there is no information available about its biology, and this study is the first to contribute to this area. Laboratory rearing is not easily maintained, and likely the protocooperation field with ants in the field is an important factor for the successful establishment of colonies. This study investigated, for the first time, the life cycle of *A. forbesi* in leaves of strawberry and determined the parameters of population growth.

2. Material and Methods

2.1. Establishment of A. forbesi colonies

Aphids were obtained on 'Camino Real' cultivar strawberry plants of organic olericulture area in Pinhais Country, Paraná, Brazil (25°25′S, 49°08′W, 930m). The aphids were transferred to 'Albion' strawberry potted plants in a greenhouse, where their rearing was established.

2.2. A. forbesi biological experiment

The experiment was carried out in a climate-controlled room (at 25 ± 2 °C, with relative humidity of 60 ± 10% and a 12 h photophase). Strawberry leaves were collected and placed in separated petri dishes (1.3 cm high × 6.5 cm in diameter), which contained a background layer of 3 mm of water-agar (3%) and nipagim (5%), forming arenas. The tip of the leaf stem was capped with a small piece of wet cotton to avoid the leaf from drying out.

Three adult females of the strawberry root aphid were placed on each plate with the help of a slim paintbrush to allow reproduction. After 24 hours later, only one nymph was left per plate and the biological parameters were recorded. Everytime that the leaf showed any signs of senescence, it was changed by another. The duration and viability of the nymphal instars were determined daily by observations through a stereoscopic microscope, increasing at a power of 10 X, with the removal of exuviae. The nymphs obtained were counted to determine the daily and total production for each adult. Subsequently, the nymphs were removed, leaving just the adult.

The following biological parameters of *A. forbesi* were measured: survival during the nymphal stage, duration of each nymphal stage and total nymphal stage, adult, pre-reproductive, reproductive and post-reproductive periods, as well as longevity, total fertility and life cycle.

With the data obtained from *A. forbesi* biology were calculated the parameters used in the fertility life table, namely: (r_m), defined as the maximum rate of increase achieved by a population with a fixed age distribution, over any timespan, under optimum space and feeding conditions, and without the influence of other factors (Andrewartha and Birch, 1954); (DT) indicates time needed for the population double in number (Coats, 1976; Rabinovich, 1978); (T), the mean interval between generations, is the average length of a generation; (R_o), the net reproductive rate, is the total of female offspring produced per female during the reproduction period, that arrive to the next generation; (λ), the finite rate of increase, is the number of times that the population multiplies in a unit time.

2.3. Experimental design and analysis of data

The fertility life table was developed and the parameters of population growth were estimated. The mean interval between generations (T), the net reproductive rate (R_o), the intrinsic rate of increase (r_m), the finite rate of increase (λ), and the time required for the population to double in number (DT) were calculated using the *TabVida* software, such as Penteado (2007) and Penteado et al. (2010) described. The experiment had a randomized design with 100 replicates.

3. Results

Of all the aphids evaluated, 25% completed the biological cycle in four nymphal instars, 46% in three instars and 29% did not complete the cycle.

The nymphal stage took between 6.5 and 7.2 days, respectively in three or four instars (Table 1).

The mean pre-reproductive period of the strawberry root aphid was 2.0 and 2.5 days for the aphids with three and four instars, respectively. The length of the reproductive period ranged from 6.6 to nine days, with a mean of 5.6 and 8.2 days for the aphids with four and three instars, respectively. The lengths of the post-reproductive period were 1.9 and 2.1 days for the aphids with four and three instars, respectively.

The mean longevity values of the aphids with four and three instars were 8.4 and 11.6 days, respectively; with mean biological cycle times of 15.6 and 18.11 days. The aphids with three and four instars produced 1.4 and 1.5 female nymphs per day, respectively, with the total number of nymphs per female being 11.50 and 8.23 (Table 1). The viability of each instar was high, exceeding 90%.

Table 1. Biological parameters (mean ± standard error) of *Aphis forbesi* fed on strawberry leaves (*Fragaria* × *ananassa* 'Albion') at 25 ± 2 °C, 60 ± 10% UR, 12-h photoperiod.

Biological parameters (days)	With 3 instars*			With 4 instars**			Viability (%)		
	Mean	±	SE	Mean	±	SE	Mean	±	SE
First instar	1.8	±	0.1	1.1	±	0.1	99	±	1.81
Second instar	2.3	±	0.1	1.9	±	0.3	96	±	6.10
Third instar	2.4	±	0.1	2.2	±	0.2	95	±	7.62
Fourth instar	–			2.0	±	0.2	94	±	8.57
Nymphal stage	6.5	±	0.2	7.2	±	0.4	96	±	1.50
Pre-reproductive period	2.0	±	0.2	2.5	±	0.4			
Reproductive period	8.2	±	0.8	5.6	±	1			
Post-reprodutive period	2.1	±	0.3	1.9	±	0.3			
Longevity	11.6	±	0.9	8.4	±	0.8			
Total nymphs/female (n)	11.5	±	1.2	8.2	±	1.7			
Nymphs/female/day (n)	1.4	±	0.1	1.5	±	0.3			
Biological cycle (days)	18.1	±	0.9	15.6	±	0.8			

*n=46 to 3 instars. **n=25 to 4 instars.

The highest percentage of *A. forbesi* survival occurred in the first instar (99%), gradually decreasing through the fourth instar (Table 1).

The mean interval between generations (T) was, on average, 11.3 and 11.81 days, and the net reproduction rate (R_0) was 5.81 and 9.12 for aphids that had four and three instars, respectively (Table 2).

The intrinsic rate of increase (r_m) values for *A. forbesi* with four and three instars was 0.1557 and 0.1872, respectively. The aphids with four and three instars had a finite rate of increase (λ) values of 1.1685 and 1.2059, respectively.

The time needed for the population to duplicate in number (DT) for the aphids with three and four instars were 3.70 and 4.45 days, respectively.

Table 2. Parameters of population growth for *Aphis forbesi* fed at strawberry leaves (*Fragaria* × *ananassa* 'Albion') (25 ± 2 °C, 60 ± 10% UR, 12-h photoperiod).

Parameters	Three nymphal instars	Four nymphal instars
Time between each generation (T)	11.81	11.3
Net reproduction rate (R_0)	9.12	5.81
Intrinsic rate of increase (r_m)	0.1872	0.1557
Finite rate of increase (ʎ)	1.21	1.17
Time for the population double in number (TD)	3.70	4.45

4. Discussion

It was observed in the field that this species develops on the petioles and roots of strawberries, and can coexist with *C. fragaefolli* colonies in the same plant. But, the aphid *C. fragaefolli* usually occurs on new shoots, in the crown, and close to the veins on the undersides of leaflets (Bernardi et al., 2012; Rondon and Cantliffe, 2015). Both are species associated with strawberry crops and could damage them (Bernardi et al., 2012). Since there is no information available about *A. forbesi* biology in strawberries, this discussion will be based primarily on data obtained for *C. fragaefolli*.

A. forbesi was able to complete the biological cycle on strawberries leaves, exhibiting three and four nymphal instars, although most exhibited three, which is probably the norm. These results are different from the results of Dixon (1987) and Minks and Harrewijn (1987), who reported that aphids generally undergo four nymphal instars, although part of the population will only undergo three (Kairo and Murphy, 1999). Bernardi et al. (2012) observed four nymphal instars for *C. fragaefolii* on strawberry, however, Chagas Filho et al. (2005) and Cédola and Greco (2010) reported the existence of a fifth instar. That is, although the most common is four instars for most aphids, it is found that variations can occur in quantities of the instars.

A. forbesi completed the nymphal stage in shorter time than observed by Bernardi et al. (2012) which reported that the duration of the nymphal phase of *C. fragaefolli* ranged from 8.67 to 11.12 days when seven different strawberry cultivars were analysed in similar conditions of this experiment. In cultivar Albion, it was observed a nymphal stage of 9.74 days to *C. fragaefolli*.

The mean pre-reproductive period of the *A. forbesi* was shorter than the pre-reproductive period of the *C. fragaefolli* that fed on cultivar Albion, which was 7.43 days (Bernardi et al., 2012). The reproductive period and, consequently, the production of offspring, is an indication of acceptance of the plant as an ideal host for insect development (Minks and Harrewijn, 1987). This could mean that *A. forbesi* is well adapted in strawberry plant.

The *A. forbesi* viability of each instar was high, gradually decreasing until the fourth instar. Bernardi et al., (2012), observed a similar pattern to *C. fragaefolli*, the highest percentage of survival occurred in the first instar (94%), and gradually decreasing through the fourth instar (71%). Although the pattern was similar to *A. forbesi*, all instars had a higher percentage of survival when compared to result of *C. fragaefolli.*

The length of the reproductive period of the *A. forbesi* was shorter than the one observed in the *C. fragaefolli* by Bernardi et al., (2012) who observed a reproductive period in the *C. fragaefolli*, varying from 16.84 to 18.41 days; in the cultivar Albion these authors observed a period of 18.07 days. Cédola and Greco (2010) observed 11.8 days in the reproductive period of the *C. fragaefolli.*

Bernardi et al. (2012) found a cycle life of 17.17 days for *C. fragaefolli* in the cultivar Albion. This result was similar to *A. forbesi*. The same researchers observed that the aphids kept in cultivars Albion showed low daily nymphs by female per day (0.78) and the total fecundity was 14.09. Our results show that *A. forbesi* can reproduce more nymphs by female per day than *C. fragaefolli,* but the root aphid has a shorter life cycle so, the total fecundity was lower than that found to *C. fragaefolli.*

Every 11 days there is a new generation of *A. forbesi*, where each female has the potential to generate between 6 to 9 individuals, increasing its population by 1.2 times. (T) value to *A. forbesi* was similar to results reported by Razmjou et al. (2006) (9.06 to 10.72 days), and Michelotto et al. (2004) (10 to 10.63 days) to *Aphis gossypii* Glover, 1877 (Hemiptera: Aphididae) and is much lower than those results observed for *C. fragaefolli*, that there is a new generation every 27 days, and each female has the potential to generate 10 individuals, increasing its population by 1,1 times Bernardi et al. (2012), suggesting the potential for growth of a colony of *A. forbesi* with large number of generations in a year.

The time for the population double in number (TD) observed in the *A. forbesi* is shorter than (TD) observed by Benatto (2014) who observed in the *C. fragaefolli* 5.61 days in the cultivar Albion..

The intrinsic rate of increase (r_m) relates to (R_0) and (T), indicating the biotic potential of the species (Price, 1984; Traicevski and Ward, 2002; Penteado, 2007). The (r_m) values for *A. forbesi* were positive, to aphids that exhibited three and four instars, and biggest than the results of Bernardi et al. (2012) which found, for *C. fragaefolii* the value to (r_m) of 0.0976, it means that the birth rate exceeded the mortality rate, leading to population growth.

Coats (1976) stated that (r_m) was the most important parameter obtained from a life table because it allowed comparisons of the potential increases of species. Based on this, we can understand that *A. forbesi* could be better adapted in this strawberry cultivar than *C. fragaefolli*, because it has a higher value of (r_m) and this means being more successfull than a species in one given environment (Penteado, 2007).

The high viability observed in all instars and the results obtained in the fertility life tables suggest that *A. forbesi* has the capacity to increase its numbers in a short period of time, while generating high populations in strawberry crops, requiring differential management.

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