Effects of artificial diet on the biological characteristics of the ladybeetle *Coccinella septempunctata*

Chao LIU1,2, Hongling LIU1, Xinglong WU1, Kejun XIAO1, Hengguo HE3, Qiong HUANG2 and Deqiang PU1

1 Key Laboratory of Integrated Pest Management of Southwest Crops, Institute of Plant Protection, Sichuan Academy of Agricultural Sciences, Chengdu, China
2 College of Forestry, Sichuan Agricultural University, Wenjiang, China
3 College of Life Sciences, China West Normal University, Nanchong, China

Abstract

The ladybeetle *Coccinella septempunctata* Linnaeus is an important natural enemy of aphids, scale insects, whitefly, and lepidopteran larvae. Mass rearing of this natural enemy is limited due to the lack of effective artificial feed. We compared the biological performance of *C. septempunctata*, reared on four artificial diets (A, B, C, and D), while the pea aphid *Aphis craccivora* served as a control treatment (CK). Results showed that the developmental time before emergence ranked from short to long follow as: CK (12.30d) < D (16.66d) < A (17.38d) < C (17.54d) < B (18.57d). The eclosion rate of larvae ranked from high to low follow as: CK (90.00%) = D (87.50%) = C (87.50%) > B (80.00%) > A (57.50%), and new adult weight from high to low follow as: CK (339.50 g*0.0001) > A (205.33 g*0.0001) > D (197.68 g*0.0001) > B (174.89 g*0.0001) > C (169.46 g*0.0001). The ratios of fecundity between the experimental group and the control group were 80.46% (A), 39.24% (B), 45.31% (C), and 53.02% (D). The hatch rates were 59.50% (A), 46.00% (B), 57.65% (C), 54.50% (D), and 53.88% (CK). The mortality of *C. septempunctata* adults fed on a combined artificial diet was higher than those fed on the control diet. Compared to the control diet, *C. septempunctata* did not significantly reduce oviposition when fed on artificial diet A. Therefore, diet A can be used in mass-rearing of *C. septempunctata*.

Key words: aphid, artificial diet, biocontrol, *Coccinella septempunctata* Linnaeus

Introduction

Ladybeetle *C. septempunctata* Linnaeus is an important natural enemy in agricultural and forestry ecosystems in Africa, Europe, and Asia. This species has the characteristics of large predation, wide predation range, reproductive ability, and adaptability, especially strong cold resistance, suitable for the prevention and control of aphids in early spring. It has a wide range of application prospects. Adults and larvae *C. septempunctata* can prey on eggs and larvae of a variety of aphids, whitefly, and lepidopteran larvae. *C. septempunctata* has been widely researched in preventing and controlling aphids, whiteflies, thrips on crops and trees. To ensure control efficacy to the pests, a sufficient number of natural enemies should be released (Skouras *et al.* 2015; Zhang *et al.* 2014). Therefore, an efficient and large-scale rearing of *C. septempunctata* is needed to meet this objective.

In the 1950s, the first artificial diet for insects was prepared with prey dry powder as the main component, and a variety of predatory ladybugs were successfully raised on this diet (Sminoff 1958). The effects of various nutrient components (amino acids, cholesterol, vitamins, etc.) on the growth and development of *Harmonia axyridis* (Pallas) were analyzed.
and the results showed that larvae did not develop successfully and the adults did not lay eggs (Niijima et al. 1977). Later, research on artificial diets for ladybugs changed from prey components to non-prey components and even non-insect source components. Artificial components such as pork liver, yolk, honey, Spodoptera frugiperda, bee pupae, and yellow mealworm were trialed. In recent years, nearly 100 formulas have been trialed, but the problem of low oviposition rate and hatch rate has not been well solved (Ashraf et al. 2010; Doddamani et al. 2018; Puysséleyr et al. 2014; Racipoli et al. 1981; Rojas et al. 2016; Sarwar 2010; Sighinolfi et al. 2008; Silva et al. 2013; Venkatesan et al. 1998; Zou et al. 2013). Another study in China used an orthogonal design and included 16 selected factors tested at two levels, which was carried out to improve the artificial diet of C. septempunctata adult, weight gain, and fecundity of adults reared on this diet were respectively 87.46% and 62.70% of those reared on Aphis craccivora (Cheng et al. 2018). However, these artificial feeds have certain adverse effects on emergence rate, oviposition rate, hatch rate, etc., in ladybirds. In particular, low egg production and hatch rates seriously restrict the development of ladybird artificial breeding, thus hindering ladybird use in large-scale production.

In our previous research, we found that the emergence rate of larvae of C. septempunctata and the weight of newly emerging adults and fecundity fed purely with artificial diets were significantly lower than those of C. septempunctata fed by aphids (Zeng et al. 2020). Therefore, we used a combination of both artificial feed and aphids to raise C. septempunctata. In order to clarify the effects of artificial feed and different feeding methods on the larvae and adults of C. septempunctata, we compared the development of C. septempunctata larvae and the biological indicators such as fecundity, longevity, emergence time, etc. of adults with different feeding methods in this study.

Materials and methods

Materials

Ladybeetle colonies: The population of C. septempunctata was continuously raised for more than 10 generations on A. craccivora Koch in an insectary at the Institute of Plant Protection, Sichuan Academy of Agricultural Sciences. The original population was collected from Mianning County, Liangshan Yi Autonomous Prefecture, Sichuan Province, China (E102.17, N28.55). The population of adults for each generation was 600 and the proportion of females was 55.4%. The newly hatched larvae were continuously fed on the aphids until the adults mated. The adult mating pairs were collected and raised in separate Petri dishes (90 mm). C. septempunctata were maintained in the laboratory at 25 ± 1°C and a 75% ± 7% relative humidity, with a 10: 14 h (light: dark) photoperiod using a 18,000 LX fluorescent lamp.

Aphids rearing: The population of aphids (A. craccivora Koch) was raised for more than 10 generations on Vicia faba L in an insectary at the Institute of Plant Protection, Sichuan Academy of Agricultural Sciences. The original population was collected from Qingbaijiang District, Chengdu City, Sichuan Province, China (E104.23, N30.88).

Artificial feed production

Four artificial feed diets with different formulas were prepared in the laboratory. Diets A, B, and C were dry powder feeds, while diet D was a paste feed. In order to preserve the nutritional content of the paste feed and prevent the dry powder feed from becoming deliquescent and moldy, the paste diet was stored for a maximum of 15 days in a freezer at −20°C, while the dry powder feeds were stored for a maximum of 30 days at 4°C for future use.

The composition of all diets is shown in Table 1. The bee pupae, silkworm and Tenebrio molitor and pork liver used in this study were all obtained commercially. In the laboratory, pork liver was dried at 55°C for 48 hours, fresh bananas were sliced and dried at 60°C for 96 hours and fresh aphids were dried at 55°C for 24 hours. All dried materials were crushed in turn by a shredder and stored at 4°C for later experiments. Diet A, B, and C were weighed in sequence according to the various formulas and stirred evenly (Table 1). Diet D was prepared in a hot water bath by adding raw materials in the order presented in Table 1. Agar was added last and the artificial feed was placed at 4°C to cool and solidify. The prepared dry powder and paste feed were stored in the refrigerator at 4°C for later use.

C. septempunctata selection and feeding

Larva feeding

This experiment involved a total of five treatments. The test group consisted of the four artificial diet feeding groups, while the control was the aphid feeding group (CK). The newly hatched C. septempunctata larvae were selected and reared separately in transparent plastic boxes. The dimensions of the boxes were 110 mm width × 60 mm height × 170 mm length and a thickness of 0.5 mm. A portion of the box cover was removed and replaced with a 200-mesh nylon gauze to maintain air permeability. Larvae in each box were fed with aphids for three days, and then fed artificial feed for three consecutive days, then fed aphids for one day, and so on, until the larvae pupated. There were four boxes in each treatment and 10 larvae in each box. Diets A, B, and C were mixed with 10% sucrose liquid at a ratio of 2:10 and the larvae were fed on...
them in the same way as diet D. For the CK group, larvae in each box were fed with aphids until the larvae pupated.

Adult feeding
This experiment involved a total of five treatments. The test group consisted of four artificial diet feeding groups, while the control was the aphid feeding group (CK). Each treatment had 30 replicates and each replicate consisted of a male and a female ladybug. Emerged adults which mated the first time were caught in pairs in Petri dishes with one pair per dish. They were fed aphids until the first spawning, and then used for later experiments.

Feeding tests on diets A, B, C, and D.
Ladybeetles were fed on a combination of an artificial diet and aphids after adults spawned. They were fed with the artificial diet for three days, followed by aphids (~200 per dish) for one day, and then fed with an artificial diet for three days, followed by aphids (~200 per dish) for one day, etc. The artificial diet was kept in cylindrical plastic containers (diameter 2 cm, height 1 cm), and absorbent cotton soaked in 10% sucrose liquid (sucrose: purified water = 1:9) was placed in another cylindrical plastic container for A, B, and C. In order to ensure that diet D was always fresh, it was kept in a cylindrical plastic container (diameter 2 cm, height 1 cm) and changed every day at 10:00 am.

In the control groups, adult ladybeetles started feeding on aphids after ovipositing for the first time in Petri dishes. In order to ensure that a constant number of aphids were available in all treatments, aphids were changed every day at 10:00 am with 200 new aphids.

Observation
For larval, the time from hatching to the emergence of larvae, the number of emergent adults and the weight of new adults were recorded. For adults, feeding frequency was observed at 8-day intervals. Each culture dish was observed every 5 minutes, from 15:00 to 16:00 on the first day after feeding on either the artificial feed or aphids. If the behavior of feeding was observed, it was recorded as 1, if there was no feeding, it was recorded as 0. Mating frequency was observed at 8-day intervals. Each culture dish was observed every 5 minutes, from 15:00 to 16:00 on the first day after feeding on either the artificial feed or aphids. If mating was observed, it was recorded as 1, if there was no mating, it was recorded as 0.

The eggs of *C. septempunctata* were collected from the Petri dishes at 9:00 h, 12:00 h, 14:00 h, and 17:00 h daily and their numbers were counted. The number of eggs and the date on which they were collected was recorded. The collected eggs were placed in corresponding Petri dishes and kept under controlled laboratory temperature conditions for hatching. When the eggs hatched, the number of eggs per egg mass in

### Table 1 Composition of artificial feed

| Artificial Feed | A | B | C | D |
|-----------------|---|---|---|---|
| *A. mellifera* pupae | 30 g | 0 g | 0 g | 30 g |
| *B. mori* pupae | 0 g | 30 g | 0 g | 0 g |
| *T. molitor* pupae | 115 g | 115 g | 115 g | 115 g |
| Sucoase | 20 g | 20 g | 20 g | 20 g |
| Pork liver | 10 g | 10 g | 10 g | 10 g |
| Rapeseed pollen | 0 g | 0 g | 0 g | 0 g |
| Aphid | 1 g | 1 g | 1 g | 1 g |
| Beta carotene | 2 g | 2 g | 2 g | 2 g |
| Olive oil | 0 g | 0 g | 0 g | 5 g |
| Banana | 0 g | 0 g | 0 g | 89.5 g |
| Agar | 900 g | 900 g | 900 g | 900 g |

Note: *A. mellifera*, *B. mori*, *T. molitor*, pork liver, rapeseed pollen, aphid, and banana were made in dry powder. Sucrose water was not mixed with dry powder.
each Petri dish was recorded. Mortality of adult *C. septempunctata* in each Petri dish was checked and recorded every day. The mortality rate was calculated for each treatment. Adult pairs were weighed before they were put into the Petri dishes, then weighed every 12 days, for a total of six times for each pair.

**Data analysis**

Data is presented as the mean values and standard mean errors using descriptive statistics. The developmental duration of larvae was calculated by the time from egg hatched to successful emergence into adults, the emergence rate was calculated by dividing the number of new adults by the number of larvae, and the new adults were fed with aphids for three days and then weighed. A total of eight intervals were made for each group for feeding and mating, the feeding and mating frequencies of adults were calculated by the total value divided by eight. The fecundity of each Petri dish was calculated by the sum of all eggs in 60 days. The hatch rate was calculated by dividing the number of new larvae by the number of eggs, and the average hatch rate of eggs for each 60-day period for each repeat group was used for data analysis. A total of five weights and deaths were counted. The average body weight of each repeated treatment was used for analysis. All data used one-way ANOVA, P values < 0.05 were considered significant. All statistical analyses were performed using SPSS 16.0 software.

**Results**

**Larvae development**

As shown in Table 2, the developmental time of larvae in the CK group was significantly shorter than in other groups (p < 0.010). The developmental time of larvae in group D was significantly shorter compared to the developmental time of group B (p = 0.004) (Table 2). The emergence rate ranked from high to low was: CK (90.00 ± 0.04%) > C (87.50 ± 0.03%) = D (87.50 ± 0.05%) > B (80.00 ± 0.04%) > A (57.50 ± 0.04%). The emergence rate of group A was significantly lower than other groups (p < 0.010, n = 4). There was no significant difference among the other groups (p > 0.050, n = 4). The average weight of adults ranked from high to low was: CK (339.50 ± 7.88 g*0.0001) > A (205.33 ± 7.60 g*0.0001) > D (197.68 ± 8.72 g*0.0001) > B (174.89 ± 6.90 g*0.0001) > C (169.46 ± 5.71 g*0.0001). The average weight of adults in the CK group was significantly higher than the other four groups (p < 0.010), and groups A and D were significantly higher than groups B and C.
Feeding and mating frequency

As shown in Figure 1, the feeding frequencies of adults fed on different diets was: D (46.37 ± 6.84, n = 8) > A (42.37 ± 8.79, n = 8) > B (32.75 ± 6.73, n = 8) > C (26.37 ± 6.81, n = 8) > CK (19.75 ± 2.70, n = 8). The feeding frequency of A and D are significantly higher than that of the control group (p = 0.022, p = 0.008, n = 8), and there was no significant difference among B, C, and the control group (p = 0.178, p = 0.488, n = 8). There was no significant difference among groups A, B, C, and D (p > 0.05, n = 8).

As shown in Figure 1, the mating frequencies of adults fed on different diets ranked as: CK (30.87 ± 5.59, n = 8) > D (20.62 ± 3.86, n = 8) > B (18.50 ± 5.25, n = 8) > C (18.50 ± 2.38, n = 8) > A (17.00 ± 3.63, n = 8). The mating frequencies of adults fed on diets A, B, and C were significantly lower than that of the control group (p = 0.029, p = 0.048, p = 0.049, n = 8). There was no significant difference in mating frequencies among group A, B, C, and D (p > 0.05, n = 8).

Spawning and hatching

As shown in Figure 2, the average fecundity of C. septempunctata on diets A, B, C, and D were lower than that of the control group, which were 80.46%, 39.24%, 45.31%, and 53.02% respectively. There was no significant difference between the fecundity of ladybeetles fed on diet A and the control group (p = 0.080, n = 30). However, the fecundity of the beetles which fed on diets B, C, and D was significantly lower than that of the control group (p < 0.001, n = 30).

Figure 1  Average frequency of feeding and mating within one hour per group.

Figure 2  Fecundity of C. septempunctata per pair over a 60-day period. Different lowercase letters indicate significant differences at the 0.050 level, and the same letters indicate no significant differences.
The fecundity of beetles which fed on diet A was significantly higher than those fed on diets B, C, and D (p < 0.001, p = 0.002, p = 0.0014, n = 30). There was no significant difference among the fecundity of ladybeetles that fed on diets B, C, and D (p > 0.050, n = 30).

As shown in Figure 3, the hatch rate of eggs from adults which fed on different diets ranked from high to low was: A (63.15 ± 2.61%, n = 30) > B (62.29 ± 3.42%, n = 30) > CK (60.28 ± 3.58%, n = 30) > C (59.23 ± 3.41%, n = 30) > D (58.42 ± 2.57%, n = 30). There was no significant difference among the fecundity of ladybeetles that fed on diets B, C, and D (p > 0.050, n = 30).

Changes in weight and mortality
As shown in Figure 4, the body weight of adults fed on each diet fluctuated, but the change was relatively stable on diets A, B, C, and D. However, the control group lost weight quickly after 36 days. At the end of the experiment, the body weight of the adults fed on diets A, B, C, and D were significantly higher than those fed on the control group (p = 0.018, p = 0.023, p = 0.040, p = 0.028, n = 5).

As shown in Figure 5, the mortality rate of adults from each group increased, but the mortality rate was relatively stable when fed on diets A, B, C, and D, in the control group, the mortality rate increased rapidly. At the end of the experiment, the mortality rate of adults fed on diets A, B, C, and D was significantly lower than the control group (p < 0.010, n = 3).

Discussion
Larvae development
In group D, the average developmental duration was 16.66 ± 0.28 d and the average emergence rate was 87.50 ± 0.05% which was the closest to those of the CK group, which had an average developmental duration of 12.30 ± 0.10 d and an average emergence rate of 90.00 ± 0.04%. The average weight of group D is 197.68 ± 8.72 g*0.0001, and the average weight of group A is 205.33 ± 7.60 g*0.0001, which is the closest to the average control weight. By comparing the three indicators of larval feeding (developmental duration, newly emerged adults and weight), we found that the effects of diet D and the control diet on larvae were similar. The emergence rate of larvae fed on diet A (57.50 ± 0.04%) was the lowest, indicating that diet D was better than diet A. Silkworm pupa and yellow mealworm pupae were more suitable as protein sources for larval feeds. Follow-up experiments should further assess the effect of silkworm pupae and yellow mealworm pupae as protein sources in paste feed for larval feeding. The emergence rate of each experimental group was low. The body weight of newly emerged adults was significantly lower than the control group, but the developmental time was significantly longer.
This is similar to the results reported by Cheng et al. (2018). All these phenomena showed that the four artificial feeds could not meet the growth and development needs of the larvae.

**Frequency of mating and feeding due to different artificial diet**

The mating frequency of beetles fed on diet B showed a decreasing trend first and then an increasing trend. However, the beetles fed on other diets showed the opposite trend. This was consistent with the peak of spawning in 10–30 days after the start of feeding on aphids. The decline in mating frequency, hatch rate, weight loss, and feeding frequency in the later period may be related to the aging of the *C. septempunctata*. As the adults aged, its ability to feed and digest also declined.

The influence of water content on the ingestion of *C. septempuncta* was studied by using artificial feed based on fresh pig’s liver. The results showed that 75% moisture content in the feed was the most suitable for the growth and development in the beetles. The addition of vegetable oil and ZR512 showed that lipids and nitrogen-containing substances could increase the survival rate of *C. septempunctata* and promote feeding (Chen et al. 1984, 1989; Zhai et al. 1987). Artificial diet D in this study was a paste and the moisture ratio was closest to that of natural aphids. The water was replenished during feeding and in this diet, we observed the highest feeding frequency. However, due to the insufficient nutrient concentration resulting from water dilution, *C. septempunctata* produced fewer eggs than those fed on diet A. Honey and sucrose were commonly used as feeding boosters in the development of artificial feeds for *H. axyridis* Pallas (Lü et al. 2015). In addition, soy, corn, rapeseed, olive oil, and other fats can also play a role in feeding stimulation.

### Spawning affected by different artificial feed

The fecundity of *C. septempunctata* fed on artificial diets B, C, and D were lower than those fed on other diets. This may be attributed to the lack of important nutrients in the diet or the failure of *C. septempunctata* to eat, digest, and absorb nutrients from the artificial diets. When fed with an artificial diet containing egg yolk, sucrose, honey, casein, and protein hydrolysate, *C. septempunctata* successfully reproduced offspring, but the fecundity was not high (Sarwar 2010). Generally, the biological characteristics of the stink bug, *Orius laevigatus*, were low when they were reared for four generations on artificial feed. The developmental time of nymphs was longer, the weight of eggs and adults was reduced, and likewise the fertility and hatch rate. Moreover, the self-mutilation rate of eggs and adults was higher (Puysseleyr et al. 2014). Additionally, when *H. axyridis* was fed on artificial feed consisting of shrimp, beef, beef liver, and egg yolk in a ratio of 5:4:8:4, no spawning was observed (Intazar et al. 2016). *C. septempunctata* females hardly laid eggs when they were fed on *Hypera postica* larvae, whereas fecundity increased when aphids were provided at the same time (Evans et al. 2004). This means that the aphids contained key nutrients essential for the rearing of *C. septempunctata*. In this experiment, when using 75% artificial feed instead of aphids to feed ladybeetles, the fecundity of the ladybug which fed on diet A reached 80.46% compared to those fed on the control group. The hatch rate was also slightly higher. A hatch rate of 88.56% was obtained by multiplying the fecundity and hatch rate recorded for adults fed on diet A, compared to the control group. Although a 3:1 ratio of artificial feed A to aphids can achieve better cost-effectiveness, much work still needs to be studied.

Throughout the feeding period, the fecundity of *C. septempunctata* decreased sharply on the third day for each feeding group. It has been reported that adding juvenile hormone analogues to artificial feed may also increase the
fecundity of *C. septempunctata* (Zhang & Zhai 1985). The feeding and digestive ability of *C. septempunctata* adults used in this experiment decreased gradually as they aged. In addition, the hatching rate of the eggs was also reduced and the number of abnormal eggs increased. There was no significant difference in hatch rate between the adults of each test diet and those fed on the control group. This indicated that the hatch rate of the egg masses produced by beetles fed on the artificial diets could be similar to those fed on the control diet. The artificial feed studied by Yazdani and Zarabi (2011), also showed no significant difference between the emergence rate and the hatch rate of offspring eggs in *Clitostethus arcuatus*.

**Weight and mortality affected by different artificial diet**

“Reproductive costs” is an important life-history theory and reproductive development in insects consumes a large amount of energy and nutrients (Ziomkiewicz et al. 2017). *C. septempunctata* reared on an artificial diet had longer life longevity (Ashraf et al. 2010). Therefore, compared with infertile individuals, they had a longer life span and higher resistance to stress, such as reduced fertility in the future. The results showed that adults fed on the control diet had the highest mortality, the fastest weight loss, and the highest spawning rate. The addition of lipids to the artificial diet may be responsible, as the survival rate of *C. septempunctata* increased when fed on an artificial diet that had added lipid and nitrogen-containing substances such as vegetable oil and ZR512 (Chen et al. 1984, 1989). The life span of *Delphastus catalinae* Horn fed on an artificial diet was close to 90 days, which was similar to the control group that fed on whitefly prey. However, no spawning was observed. Similarly, when *Clitostethus arcuatus* adults fed on *Siphoninus phillyreae* and *Trialeurodes vaporariorum* they had a higher fecundity rate and longer life span than when they fed on an artificial diet composed mainly of honey, yeast powder, and pollen (Yazdani & Zarabi 2011).

**Conclusion**

In summary, three types of insect protein sources, bee pupae, silkworm pupae, and yellow mealworm pupae, were compared among three diets A, B, and C. For larvae, we found that diet D is closer to the feeding result of CK diet, but overall, the results from the artificial diets are not satisfactory for the nutritional requirements of *C. septempunctata*. The nutritional requirements of larvae and adults are different and the bee pupae had the best effect on adults. The fecundity of each female adult fed on diet A (426.87 ± 82.23, n = 30) was lower than those fed on bean aphids (530.53 ± 65.67, n = 30) and they also had the lowest mortality rate compared to all the other diets, including the control diet. Diet A and D had bee pupae as the insect protein source, but the spawning rate of adults fed on diet D was 65% compared to those fed on diet A. In addition, the physical food state affects the highest feeding frequency. However, due to the dilution of its nutrients, the oviposition rate of the adults feeding this kind of food became lower. Therefore, this paste diet is not suitable for adults. Tan et al. (2015) found that a micro-encapsulated artificial diet can directly increase the efficiency and stability of mass rearing in the ladybird *Propylea japonica*, compared to using a liquid artificial diet. The addition of exogenous animal proteins to artificial diets showed that defatted powder made from fly pupae and yellow mealworm pupae had a better feeding effect than other protein forms. Further experiments should be conducted to assess the effect of adding degreased insect protein sources and trace additives such as juvenile hormone analogues to artificial feeds (Wang et al. 2008).

This study clarified the effects of four new artificial diets for ladybirds using *Apis mellifera*, *Bombyx mori*, and *T. molitor* insect protein sources and two feeding forms, dry powder feed and paste feed. Artificial feed and aphids were used to feed ladybirds alternately to reduce the impact of 75% of the aphids on the biological characteristics of *C. septempunctata* larvae and adults. Using bee pupae as the core material in the artificial feed, resulting in a better breeding method for adult *C. septempunctata*. Larvae feeding is more suitable for using paste feed versus dry powder feed. Overall, the results presented in this paper can contribute to the large-scale breeding of *C. septempunctata*.

**Author Contributions**

D.Q.P. planned experiments and contributed in writing the paper, C.L. and H.L.L. executed most of the experiments, analyzed data and wrote the paper, X.L.W. and K.J.X. raised the population of *C. septempunctata* and broadbean *V. faba* L., H.G.H. and Q.H. contributed writing the paper and intellectual contributions during the implementation of this study.

**Acknowledgments**

This research was funded by the Frontier discipline Fund of Sichuan Academy of Agricultural Sciences [2019QYXK032], key scientific and technological projects of Sichuan Tobacco Company [SCYC201805], Sichuan Tea Innovation Team of National Modern Agricultural Industry Technology System [sxctd-2020-10], and National Key R & D Program of China [2016YFD0200900, 2018YFD0201300], all of China.
Conflict of Interest

The authors declare no conflict of interest.

References

Ashraf M, Ishtiaq M, Asif M et al. (2010) A study on laboratory rearing of lady bird beetle (Coccinella septempunctata) to observe its fecundity and longevity on natural and artificial diets. International Journal of Biology 2: 165–173.

Chen ZH, Qin JD, Fan XM et al. (1984) Effects of adding lipids and juvenoid into the artificial diet on feeding and reproduction of Coccinella Septempunctata. Acta Entomologica Sinica 27: 136–146.

Cheng Y, Zhi JR, Li FL et al. (2018) Improving the artificial diet for adult of seven spotted ladybird beetle Coccinella Septempunctata L. (Coleoptera: Coccinellidae) with orthogonal design. Bulletin of Entomological Research 108: 337–343.

Doddamani VB, Behere GT, Finake DM et al. (2018) Evaluation of artificial diets for laboratory rearing of Coccinella Septempunctata L. (Coleoptera: Coccinellidae). Indian Journal of Entomology 80: 489–493.

Evans EW, Richards DR, Kalaskar A (2004) Using food for different purposes: Female responses to prey in the predator Coccinella Septempunctata (Coleoptera: Coccinellidae). Ecological Entomology 29: 27–34.

Intazar A, Zhang S, Luo JY et al. (2016) Artificial diet development and its effect on the reproductive performances of Propylea japonica and Harmonia axyridis. Journal of Asia-Pacific Entomology 19: 289–293.

Lü XD, Liu SC, Jia HR et al. (2015) Present situation and progress on artificial diet for Harmonia axyridis. Shanxi Forestry Science and Technology 44: 35–37.

Nijjima K, Nishimura R, Matsuka M (1977) Nutritional studies of an aphidophagous coccinellid Harmonia axyridis. III. Rearing of larvae using a chemically defined diet and fractions of drone honeybee powder. BioControl 17: 45–51.

Puyseleyr VD, Hofte M, Clercq PD (2014) Continuous rearing of the predatory antechinorid Orius laevigatus without plant materials. Journal of Applied Entomology 138: 45–51.

Racioppo JV, Burton RL, Eikenbar R (1981) The effects of various oligidic synthetic diets on the growth of Hippodamia convergens. Entomologia Experimentalis et Applicata 30: 68–72.

Rojas MG, Morales-Ramos JA, Riddick EW (2016) Use of Tenebrio molitor (Coleoptera: Tenebrionidae) powder to enhance artificial diet formulations for Coleomegilla maculata (Coleoptera: Coccinellidae). BioControl 100: 70–78.

Ziolkiewicz A, Frumkin A, Zhang Y (2017) The cost of reproduction in women: Reproductive effort and oxidative stress in premenopausal and postmenopausal American women. American Journal of Human Biology: The Official Journal of the Human Biology Council 30: e23069.