A Novel Method to Evaluate the Reproductive Potential of *Phymastichus coffea* (Hymenoptera: Eulophidae) in *Hypothenemus hampei* (Coleoptera: Curculionidae: Scolytinae) Under Laboratory Conditions

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Abstract

Life fertility tables were constructed for *Phymastichus coffea* LaSalle, the only known endoparasitoid wasp that attacks the adult female of the coffee berry borer (CBB) *Hypothenemus hampei* Ferrari. No preoviposition period was observed, and the parasitoid female attacked the CBB females immediately after emergence. The reproductive period was 20.33 (±0.87 SE) h and the postreproductive period of 14.78 (±0.99 SE) h. Mean generation time was 37 d. Median longevity for female and male fed on honey-water solution (50:50) was 35.22 (±1.18 SE) and 17.16 (±0.96 SE) h, respectively. The highest oviposition values were observed during the first 4 h after emergence. The sex ratio (F:M) was 1.11 (±0.31 SE): 1.04 (±0.32 SE) with a finite rate of increase (λ) of 1.06 (±0.002 SE) wasp per days and a *r*<sub>m</sub> value of 0.067 (±0.002 SE). Gross fecundity (*M*) and net fecundity (*m*) were 19.87 (±1.57 SE) males and females per female and 10.9 (±0.88 SE) females per female, respectively. The net reproductive rate (*R*<sub>n</sub>) was 9.49 (±0.75 SE) female per wasp. This study was designed to quantify reproductive rates of *P. coffea* in CBB females reared on artificial diets and used to improve a mass rearing system for this parasitoid.

Key words: demographic parameters, African parasitoid, coffee berry borer, *Phymastichus coffea*, mass-rearing.

The coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari) is the most important insect pest of all *Coffee* spp. Coffee production (*Coffeea arabica* L.) worldwide has increased by over 50% in the past 25 yr, from 93 million bags in 1990 to 143 million bags in 2015 (ICO 2015). The total value of the coffee industry during 2012 was estimated at U.S. $173 billion (Aristizabal et al. 2016). Among these strategies are the use of two African parasitoids *Cephalonomia stephanoderis* Betrem and *Prorops nasuta* Waterston (both Hymenoptera: Bethylidae) through a farmer participatory, which has been an important component of IPM programs in Colombia (Aristizabal et al. 2011, 2016, 2017).

Three parasitic wasps were introduced to Latin America against established CBB populations, included *Phymastichus coffea* LaSalle. This is the only identified endoparasitoid capable of controlling CBB adult. This parasitoid was discovered in 1988 in Togo (West Africa) by Borbon (Borbon 1989) and subsequently described by LaSalle (LaSalle 1990). It was introduced from colonies maintained in England to Mexico in 1992 and to Colombia in 1996 (Lopez-Vaamonde and Moore 1998). From Colombia, it was exported to Guatemala, Ecuador, India (Bustillo 2005), and the United States (Portilla and Streett 2006). In the United States, a mass-rearing colony was established at the USDA-ARS, Biological Control of Pests Research Unit in Starkville, Mississippi, and subsequently, this parasitoid was exported to Peru, El Salvador, Jamaica, Costa Rica, Togo, India, Ecuador, and Mexico (Portilla and Streett 2008).
Establishment has been reported in Colombia (Bustillo 2005), and according to Portilla and Streett (2008), it was recovered from coffee plantations in Jamaica, Togo, Peru, El Salvador, and Costa Rica 3 mo after its release. However, it is unknown if monitoring was continued to determine establishment success.

Several studies have been conducted to understand the taxonomy, biology, and behavior of \( P. \text{coffea} \). The parasitoid females are ~1 mm long, whereas males are half that size (LaSalle 1990). *P. \text{coffea} \) has been described as a primary, gregarious, endoparasitoid of CBB adult females (Feldhege 1992, Lopez-Vaamonde and Moore 1998, Castillo et al. 2004a). Females begin oviposition immediately after emergence, ovipositing two eggs, usually one female and one male (Infante et al. 1994). According to Espinoza et al. (2009), both female and male larvae feed inside the CBB abdomen. However, toward the end of the larval stage, the male larva migrates to the female and male larvae feed inside the CBB abdomen. However, longevity is limited to only 3 da (Feldhege 1992). Oviposition behavior is well described by Lopez-Guillen et al. (2010). Unfortunately, only a minimal number of investigations have been conducted at field sites in Colombia and Mexico (Echeverry 1999, Vergara et al. 2001, Aristizabal et al. 2004, Jaramillo et al. 2005, Espinoza et al. 2009, Infante et al. 2013). Under typical field condition, its life cycle takes 47 d (Vergara et al. 2001, Espinoza et al. 2009) and parasitism levels range from 8 to 85% and are apparently comparable between authors (Jaramillo et al. 2005, Espinoza et al. 2009, Infante et al. 2013).

Advances in large-scale rearing the African parasitoids *Cephalonomia stephanoeders* Betrem and *Prorops nasuta* Waterston (Hymenoptera: Bethylidae) reported by Portilla and Bustillo (1995) and Bustillo et al. (1996) allowed for the development of successful large-scale rearing of \( P. \text{coffea} \). To date, only two successful large-scale rearing strategies for \( P. \text{coffea} \) have been developed, by Orozco (2002) in Colombia using parchment coffee and in United States by Portilla and Streett (2008) using CBB rear on Ceribroca artificial diet.

Thirty years after \( P. \text{coffea} \)'s discovery, no published information is available on demographic parameters to allow the construction of statistical fertility tables. Therefore, this study was designed to quantify reproductive rates of \( P. \text{coffea} \) in CBB females reared on the artificial diet developed by Portilla and Streett (2008) called MP (senior author's initials). These results were used to improve a mass rearing system, as described by Portilla and Streett (2008). According to those authors, parasitoid production using MP diet may be a more feasible alternative for mass-rearing large numbers and allowing coffee producers the ability to obtain them at more reasonable costs.

### Materials and Methods

#### Insect Colonies

This study was conducted in 2006 at the USDA-ARS, Biological Control of Pests Research Unit (BCPRU), Starkville, Mississippi, under a cooperative agreement between National Federation of Colombian Coffee Growers (FEDERACAFE), USDA-ARS, and Mississippi State University. Colonies of \( H. \text{bampae} \left( F_{w}\right) \) and \( P. \text{coffea} \left( F_{m}\right) \) were used for this research. Both colonies were established in 1999 and 2001, respectively (Portilla and Streett 2008), from shipments received at the quarantine facility, Stoneville, Mississippi, from the Centro Nacional de Investigaciones del Café (CENICAFFE), Chinchina, Colombia. Both parasitoids and its host were reared according to the methods described by Portilla and Streett (2008). Rearing was carried out in an environmental room with a photoperiod of 0:24 (L:D) h, 27 ± 1°C, and 75 ± 10% RH (Portilla 1999a, b). The Ceribroca diet was used to rear CBB and MP diet to maintain the parasitized CBB female by \( P. \text{coffea} \). Ceribroca diet was prepared according to the procedures described in Portilla and Streett (2006).

#### Preparation of the Artificial Diet MP

The MP diet was prepared according to the procedures provided in Portilla and Streett (2008) with some modifications on containers and equipment. The diet consisted of 10 g of Gelcarin, 10 g of Torula Yeast *Candida utilis*, 25 g of whole chicken egg, 3 g of benzoic acid, 1.5 g of Benomil, 150 g of ground coffee beans (12% moisture content level, BUNN-O-MATIC, Coffee grinder, GSG-3BLK automatic, BUNN, Springfield, IL), and 800 ml of water. The ground coffee and gelcarin were mixed in 700 ml of water and autoclaved for 15 min at 120°C and 15-lb pressure. Twenty-five g of fresh whole chicken egg were mixed in 100 ml of distilled water using a MILLIPOR SYMPLISITY-185 (Merck, Billerica, MA) and subsequently boiled using a hot plate (CORNING PC-420, Tewksbury, MA) for ~10 min at 65°C until the viscosity was similar to scrambled eggs. The autoclaved and cooked mixtures were mixed in an industrial blender with a capacity of 4 liter (WARING-NSFND034494, Torrington, CT) for about 3 min. The remaining ingredients were subsequently added and mixed for 2 more minutes. The diet was dispensed into plastic-rearing containers using an automated dispenser pump drive (Master Flex, East Bunker, CT) calibrated to dispense 10 ml of diet per container (1 cm × 6 cm in diameter) (PIONERPLASTIC-032-6, Dixon, KY). The lid of the container was modified with one screened opening (1 cm diameter) to allow exchange of fresh air. The diet-filled containers were stored at 15°C for 2 d before use.

#### Reproductive Behavior and Biological Aspects of \( P. \text{coffea} \)

Recently emerged \( P. \text{coffea} \) parasitoids (45 female: 45 male) were used to observe their behavior and determine their prereproductive, reproductive, and postreproductive periods, and longevity. Immediately after emerging, the 45 pairs were fed once for 20 min using a cotton ball soaked in a mixture (50:50) of honey and reversed osmosis (RO) water. Parasitoids had low activity and high mortality in preliminary tests when they were placed in Petri dishes with the bases covered with MP artificial diet (parasitoids were unable to walk on diet). Therefore, to avoid high mortality, each pair was then placed in plastic containers (1 × 6 cm in diameter) (PIONERPLASTIC-032-6, Dixon, KY) with the bottom covered with white filter paper instead to facilitate wasps and host mobility. The containers with the wasps and CBB hosts were transferred to an environmental room at 25 ± 1°C, 75 ± 10% RH, and a photoperiod of 24:0 (L:D) h until all parasitoids had died. During this time, each pair of wasps was exposed to a group of 10 recently emerged CBB females. The group of CBB females was removed every 2 h and replaced with a new group until fewer or no host attacking behavior by \( P. \text{coffea} \) was observed. Subsequently, the group of CBB was replaced every 5 h until all females had died. Adult mortality in each evaluation interval was recorded and female and male parasitoids longevity quantified. After parasitoid exposure, each group of CBB was transferred to a container with the lid containing a 1-cm diameter screened opening and 10 g of MP diet, as previously described. The parasitized hosts were kept for 20 d in an environmental room with a photoperiod of 0:24 (L:D) h, 27 ± 1°C, and 75 ± 10% RH prior to dissection. During that period, immature male and female parasitoids inside the CBB female reached a distinguishable larval
stage easy to identify. The number of immature female and male parasitoids found in each dissection for each evaluation interval (CBB groups) was recorded and used to estimate the reproductive rate: prereproductive, reproductive, and postreproductive period; and sex ratio of P. coffea.

In order to calculate immature mortality of P. coffea, a second dissection was conducted by selecting three groups of 60 parasitized CBB females (60 individuals per replicate) from the main colony mentioned above. The parasitized cadaver CBB females were selected using characteristics described by Portilla and Streett (2008). Parasitized CBB females were identified by an enlarged abdomen and pronotum slightly separated from their thorax due to parasitoid development inside the body. The parasitized CBB females were placed inside plastic cages 12-cm deep by 25 cm in diameter. The lid of the cage was modified with a screened opening of 7 cm diameter, and the base was covered with a white paper towel. (Pioneer Plastic 250-C cages, Portland, OR) (Portilla and Streett 2008). The parasitized CBB females were kept inside the cage until all parasitoids emerged. Subsequently, each CBB cadaver was dissected using an OLYMPUS B061 microscope (Center Valley, PA) at various magnifications. The microscope was equipped with a Leica MC120 HD camera (Leica Microsystems, Wetzlar, Germany) and images were captured using Image Pro-Plus V4 software (Media Cybernetics, Rockville, MD). The thorax of each CBB was separated from the abdomen and dead parasitoid larvae or pupae inside were counted. The immature survival rate was calculated from the ratio of dead individuals to the total initial population. This value was used for incorporated into the survival parameter for calculating the life fertility tables.

Reproductive Rates of P. coffea

Life fertility tables were calculated according to Portilla et al. (2014) and Portilla and Grodowitz (2018). Portilla et al. (2014) explained step by step the calculations of three species of insects and their abridged cohort life table constructions based on formulae and definitions from Carey (1993) and Krebs (2001). The data are available in MS Excel spreadsheets (http://booksid.elsevier.com/9780123914538) (Portilla et al. 2014). The parameters were determined by selecting the age class (x) and number of female parasitoids surviving to age x (Nx). Using these parameters, the following model was used: lx = Nx, /Nx (where lx = the proportion of females surviving to age x, and where Nx = the number of initial females). The daily calculation of age-specific survival rate (lx) and age-specific fecundity (mx) (female progeny produced by a female of age x) was used to estimate net reproductive rate (R0 = Σ β x=α lx mx) (where β = youngest age and α = oldest age), mean generation time (T = Σ β x=α lx mx / Σ β x=α x lm x), intrinsic rate of increase (λ = eR0), and doubling time [DT = ln(2)/R0]. Calculations were done using the method of trial value r based on life fecundity incorporating sex ratio, immature percentage and developmental time (egg to adult) into the life table constructions. The developmental time of 37.34 d was used based on published work by Portilla (1999c) and Portilla and Streett (2008).

Statistical Analysis

Developmental time, preoviposition and oviposition period, longevity, and immature mortality were analyzed using a one-way analysis of variance by the general linear model (GLM) procedure (SAS Institute 2013, Cary, NC). Demographic parameters were analyzed using a randomized complete block (three replicates; 15 pairs of parasitoids per replicate). Nonparametric estimates of the survival function of P. coffea adults were compared between females and males by using PROC LIFETEST procedures in SAS (SAS 2013). Statistical differences in the survival of parasitized females and males were determined based on log-rank statistics. Differences between least square means for all variables were evaluated using a t-test. Regression equations were fitted and plotted using Sigma Plot 11 (Systat Software Inc., San Jose, CA).

Results

Biological Parameters

Phymasticus coffea successfully developed from egg to adult in H. hampei reared on the artificial diet MP. Significant differences occurred in longevity among female and male parasitoids (F = 139.47; df = 1, 89; P = 0.0001) with 35.22 ± 1.18 [SE] h determined for females and 17.16 ± 0.96 [SE] h for males (Table 1). Maximum survival was 55 h for females and 35 h for males (Fig. 1A). Female wasps parasitized CBB females, where they laid two eggs per host, producing a female and a male parasitoid per oviposition. The parasitoid showed highly significant preference to lay two eggs per host (F = 207.31; df = 1, 31; P < 0.0001). Out of 471 CBB parasitized by P. coffea, two eggs (male and female) per host were deposited in 87.19 ± 3.53% [SE] and 12.81 ± 3.53% [SE] percentage were found with one egg (female). There were no significant differences between number of eggs that produced female offspring parasitoids per female parasitoid (1.11 ± 0.31 [SE] wasp/h) and eggs that produced male offspring parasitoids per female parasitoid (1.04 ± 0.32 [SE] wasp/h; F = 0.2249) occurred (Fig. 1C). Seven life table parameters are presented in Table 2. Gross fecundity incorporating sex ratio, immature percentage and developmental time (egg to adult) into the life table constructions. The developmental time of 37.34 d was used based on published work by Portilla (1999c) and Portilla and Streett (2008).
female with a mean time of 37.39 ± 1.03 [SE] d. The daily growth rate was 1.07 ± 0.005 [SE] daughter females per female, doubling in 9.12 ± 0.54 [SE] d.

**Discussion**

*Phymastichus coffea* is an endoparasitoid that parasitizes the CBB adult females reducing their mobility and halting their reproduction. Parasitized females continued feeding for approximately 8–10 d until the eggs deposited into the abdomen hatched. Feldhege (1992) and Infante (1994) observed similar behavior, where the CBB female died 12 d after being parasitized. Apparently, the parasitoid requires an active host or at least one capable of feeding and remaining alive until the larval stage of the parasitoid is completed. *Phymastichus coffea* has a short adult longevity; in our study, female longevity ranged from 16 to 55 h with male longevity somewhat shorter ranging from 8 to 35 h (Fig. 1A). These results differed from Vergara et al. (2001), who reported a maximum longevity of 72 h for the female parasitoid, values that were obtained under field conditions with 75% of RH and a temperature of 22°C. Trejo et al. (2002) observed a maximum longevity of 121 h for females and 80 h for males obtained under laboratory conditions (23°C and 66% RH). The difference in longevity could be due to the fact that the experiments were conducted under different temperature regimes. In addition, in our study, male and female parasitoids were fed only once for 20 min, and throughout their entire life period, they were always exposed to a stressful search of a moving host. This could be a factor in having a shorter longevity than those reported by other authors. Espinoza et al. (2009) noted that female parasitoids attacked when the CBB female was boring into the coffee berries. However, they mentioned that the highest parasitism occurred when CBB females and parasitoids were released simultaneously and decreased with the time between hosts and parasitoids releases. On the other hand, Gauld and Gaston 1994 noted that the longevity maybe longer when hosts are scarcer; therefore, the wasp has to live longer in order to find a suitable number of hosts. This may explain the larger longevity obtained by Trejo et al. (2002), who kept the parasitoid fed with honey water solution without exposing the wasps to any hosts, which differed from this investigation where parasitoids were provided with host since their emergence until their dead.

*Phymastichus coffea* exhibits facultative parthenogenesis of the arenenokia type, where the female parasitizes its host before or after copulation, producing haploid males. Similar results were found in studies carried out by Infante et al. (1994) and Trejo et al. (2002), who reported that *P. coffea* does not go through a previposition period observing the parasitoid easily located its host and attack the CBB immediately after emergence. The reproductive rate of *P. coffea* obtained in this study was higher during the first hours of the wasp’s life (Fig. 1B and C). This suggested that this female parasitoid, due to its extremely short life as adult, must find host without delay.

The parasitoid oviposition patterns (Fig. 1B) (female eggs per female parasitoid and male eggs per female parasitoid) confirm that the female *P. coffea* is a gregarious endoparasitoid. Usually, a male and a female parasitoids develop in a host. The female ovisits two eggs, one female (1.11 ± 0.31 wasps) and one male (1.04 ± 0.03 wasps) per host per hour (Table 1). The sex ratio between female: male (1:0.94) confirms the results obtained by Lopez-Vaamonde and Moore (1998), Trejo et al. 2002, and Castillo et al. 2004a, who reported 1:0.98, 1.14:1, and 1:1 male:female per CBB parasitized, respectively. Castillo et al. (2004b) reported similar sex ratios in alternate Scolytinae hosts such as bark beetle, *Hypothenemus crudiae* (Panzer) (1:1), and ambrosia beetle, *Hypothenemus seriatus* (Eichhoff) (1:1), apple twig beetle, *Hypothenemus eruditus* Westwood (1:1), and ambrosia beetle, *Hypothenemus crudiae* (Panzer) (1:1). Similar results were noted by Lopez-Vaamonde and Moore (1998) with the Oriental bark beetle, *Hypothenemus obscurus* (Fabricius) (1.25:1), and *Araptus* sp. (1.2:1). In addition, Feldhege (1992) reported that this wasp has the ability to complete its attack and select the sex of its progeny, depositing its eggs in the thorax, abdomen, or between the thorax and abdomen. In our study, once the larvae emerged, both larvae females and males migrated to the part of the host that provided more resources to complete their development. Male eggs developed in the prothorax and female eggs on the metasoma. This oviposition behavior differed from Espinoza et al. (2009), who noted that a female parasitoid landed on the CBB female and oviposited two eggs into the dorsal part of the host abdomen only, then after the larvae emerged, the male migrated to the prothorax of the CBB female. In our study, the whole body of the CBB female was exposed to the
Eggs per day 11.26 ± 1.60
Gross fecundity ($M_g$) 19.87 ± 2.72
Fecundity ($m_g$) 10.90 ± 1.53
Net reproductive rate ($R_n$) 9.49 ± 1.31
Mean generation time ($T_R$) 37.39 ± 1.03
Doubling time ($DT$) 9.12 ± 0.54
Intrinsic rate of increase ($r_i$) 0.061 ± 0.004
Finite rate of increase ($\lambda$) 1.08 ± 0.005

*Total offspring/female.
†Females/female at age x.
‡Daughters/new-born female (population which increases each generation)
§Mean age of reproduction (d).
∥Time required for ($\lambda$) to doubling number.
$\perp$Rate of natural increase (daughters/female/d)
*Individuals/female/d

parasitoid female during the parasitization process, in contrast to Espinoza et al. (2009), where mainly the abdomen was exposed to the female parasitoid because the CBB female bored into the coffee berry. We observed that female parasitoids preferred to oviposit two eggs per host, where 87.19 ± 3.53% [SE] of the dissected CBB females contained both male and female larvae parasitoids. These results are comparable with Espinoza et al. (2009) who reported ~75% of cases with two eggs out of >3,000 CBB parasitized by P. coffea. This behavior could explain the trend in egg production that resulted in the female and male parasitoids presented in Fig. 1B. The 12.81 ± 3.53% [SE] CBB found with one female larva was due to either the parasitoid’s preference to lay one egg per host or the male egg did not survive.

The fecundity of P. coffea can vary depending on the physical conditions, rearing system, and the type of medium in which the host reproduced (diet or parchment coffee). Orozco (2002) obtained an average net fecundity of 7 females per female and a maximum net fecundity of 20.19 females and males per female parasitoid in parchment coffee, values similar to those obtained in this study (10.46 ± EE 0.64 average fertility and 21.0 females per female parasitoid maximum fecundity). However, he reported a maximum gross fertility of 30.15 males and female per female, values that differ with those found in this study (40.0 males and females per female parasitoid). These values also decreased when the colony size was increased to large-scale rearing levels where an average net fecundity of three females per female was observed, corroborating what was obtained by Portilla and Streett (2008).

| Parameters and units | Phymastichus coffea | Mean ± SE |
|----------------------|----------------------|-----------|
| Eggs per day         | 11.26 ± 1.60         |
| Gross fecundity      | 19.87 ± 2.72         |
| Fecundity            | 10.90 ± 1.53         |
| Net reproductive rate| 9.49 ± 1.31          |
| Mean generation time | 37.39 ± 1.03         |
| Doubling time        | 9.12 ± 0.54          |
| Intrinsic rate of increase | 0.061 ± 0.004 |
| Finite rate of increase | 1.08 ± 0.005 |

*Portilla and Streett (2008) noted that mass production of this parasitoid depends on host reproduction potential and demonstrated that CBB can be mass produced on the artificial diet Cenibroca in a cost-effective way by using a well-designed production facility. Over five million CBB females per day were produced at the BCPRU. The BCPRU was one of the few U.S. Government facilities with true mass production capabilities based on automated rearing system (Nordlund, 1994). A model of assessment of mass production of CBB and P. coffea was developed by a consultant from the University of London, Imperial College of Science Technology & Medicine (Leach, unpublished data). The model was developed based on the BCPRU facility’s full capacity (5 million capital expenditure) and the CBB and parasitoid production on artificial diets (2.5 million running cost per year). He estimated a production of 65 billion CBB females and 26 billion parasitoid females per year, with a total cost of US$196.52 per million parasitoids and U.S. $89.66/ha/year. This assessment was based for a coffee harvest distribution of a hectare of 5,000 coffee trees with ~1,500 ripe berries per tree and 5% of CBB infestation and the incorporation of the data from Lopez and Palacios (1997); IMP program for CBB in Quindio, Colombia, which included harvesting periods, cultural control (sanitation), determination of flowering, CBB infestation percentage, application of Beauveria bassiana, and chemical application.

Gutiérrez et al. (1998) working in Londrina, PR, Brazil, for 4yr developed a tritrophic simulation of the coffee cultivation system that considered the coffee crop, CBB, and its three introduced African parasitoids. Based on this simulation, the endoparasitoid eulophid P. coffea is potentially superior to the bethylid wasps including C. stephanoderis and P. nasuta. They also indicated that none of the bethylid parasitoids would be able to regulate CBB populations and that their combination would be even less efficient due to interspecific competition between parasitoids. They concluded that only P. coffea has the demographic characteristics to regulate CBB populations. Rodriguez et al. (2013, 2017) updated the coffee–CBB–parasitoids relationship simulation model developed by Gutiérrez et al. (1998) and concluded that control of CBB by augmentative releases of parasitoids in the Americas is neither effective nor stable and the introduction of additional bethylids will be detrimental. They suggested that P. coffea could provide substantial but insufficient control in zones with narrow flowering periods that concentrate the harvest periods including Londrina, PR and Brazil. In conclusion, based on the simulation model output, P. coffea will be feasible to control CBB in countries with several flowering periods throughout the year.

Ultimately, 100 yr of research have demonstrated that CBB is not an easy pest to kill. However, there are important efforts throughout these years, where practical examples of CBB control with African parasitoids (Benavides et al. 1994, Portilla and Bustillo 1995, Bustillo et al 1996, Quintero et al. 1998, Aristizabal et al. 1998, Echevery 1999, Baker 1999, Vergara 2001, Salazar and Baker 2002, Aristizabal et al. 2004, Jaramillo et al. 2005, Portilla and Streett 2008, Espinoza et al. 2009, Infante et al. 2013) have demonstrate the potential of these parasitoids as a component of an IPM strategy.

In general, the present investigation provides important information on the growth rate reproduction of P. coffea. Based on our data and those of other researchers, P. coffea could be considered a potential biological alternative to be incorporated into the IPM programs for the control of CBB. Its reproduction on a large scale is more feasible than any other natural control of this pest. Phymastichus coffea does not require CBB immature stages to complete development, like C. stephanoderis and P. nasuta, thus avoiding increased insect rearing production. Second, the “$r_i$” value of 0.067, which
represent the speed at the colony increased using artificial diet, are similar for both species. In addition, the artificial diet methodology used for CBB (Portilla and Streett 2006) and for parasitized CBB females can be modified easily for use in a semiautomated rearing system (Portilla and Streett 2008).

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