2001. The Journal of Arachnology 29:253–262

COMPARISON OF THE SURVIVAL OF THREE SPECIES OF SAC SPIDERS ON NATURAL AND ARTIFICIAL DIETS

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ABSTRACT. Three species of sac spiders were reared under laboratory conditions to investigate their survival and development. First, the effects of three artificial diets, milk + egg yolk, soybean liquid, and a combination of them, on the survival and development of *Hibana velox* were evaluated. Results over a 10 wk rearing period showed that the percentages of survival of *H. velox* reared on soybean liquid and combination diets did not differ significantly. However, the survival of *H. velox* on the milk + egg yolk diet was significantly lower than on the other two artificial diets. More molts and instars occurred in spiders raised on milk + egg yolk and on the combination diet than on the soybean liquid diet. Second, the development and percent survival of three sac spiders (*Chiracanthium inclusum*, *H. velox*, and *Trachelas volutus*) on artificial diet (i.e., the combination diet) and natural diets (i.e., citrus leafminer larvae and *Drosophila* adults) were compared. The three sac spiders developed into the adult stage on the combination diet. Similarly, all three sac spiders reared on *Drosophila* adults were able to develop to the adult stage. *Chiracanthium inclusum* and *T. volutus* reared on citrus leafminer larvae developed to the adult stage, whereas *H. velox* did not. Females of these three species that matured using combination diet and were fertilized in captivity produced 1–3 egg masses. Oviposition took place 2–7 days after mating. *Chiracanthium inclusum* had an average of 57 eggs per egg mass, whereas *H. velox* and *T. volutus* had an average of 110 and 56 eggs per egg mass, respectively.

Keywords: Laboratory rearing, sac spiders, *Chiracanthium inclusum*, *Hibana velox*, *Trachelas volutus*, citrus leafminer

The diversity of spiders in almost all agroecosystems suggests their importance as predators of insect and other arthropod pests (Whitcomb et al. 1963; Yeargan & Dondale 1974; Carroll 1980; Mansour et al. 1982; Mansour & Whitcomb 1986; Riechert & Bishop 1990; Barrion & Litsinger 1995). Baseline information on life history and biology is fundamental for ecological work and also important to further investigate the potential of spiders as biological control agents. However, life history studies have been done on very few species of spiders. One reason is the lack of reliable rearing methods to determine life histories and other biological data directly from laboratory cultures (Peck & Whitcomb 1968; Whitcomb 1967). Another reason is the lack of appropriate artificial diets. Since spiders are primarily carnivorous, they require behavioral cues from the prey to initiate attack and feeding. This makes the rearing and maintenance of spiders in the laboratory very laborious. Moreover, it appears that most spiders must feed on a variety of insect prey species to obtain the optimum nutrition for survival and reproduction (Greenstone 1979; Uetz et al. 1992). The need to rear different insect prey species makes it especially difficult to culture spiders in the laboratory. Formulation of artificial diets would greatly facilitate laboratory rearing of spiders; however, knowledge of the nutritional requirements for spiders is necessary.

It was reported that some species of wandering spiders are facultative nectar feeders (Taylor & Foster 1996). This finding inspired us to compare the survival of spiders on different artificial diets. Preliminary results of our previous study on the survival of the sac spider *Hibana velox* (Becker 1879) showed that spiders reared on soybean diet had a higher survival rate but slower rate of development than spiders reared on milk + egg yolk or on sugar solution alone (Amalin et al. 1999). This present study is a follow up of our previous experiment on the survival of *H. velox* raised on different artificial diets. We investigated the effect of different artificial diets including the previously tested (milk + egg yolk and soybean liquid) diets and a new diet (combination diet) on the survival and development of *H. velox*. The nutritional composition of each diet is evaluated in relation to the survival and development of the spider. Also, the various degrees of survival of the three species of sac spiders, *Chiracanthium inclusum* (Hentz 1847), *H. velox*, and *Trachelas volutus* Gertsch 1935 are compared when they were reared on artificial and natural diets. These sac spiders actively hunt their prey at night and during the day they hide in tubular silken capsules that they construct (hence the name ''sac spiders''). For this study, the three species of sac spiders mentioned above were selected as the test organisms because they were found associated with citrus leafminer, which is one of the major insect pests of lime in south Florida (Amalin 1999).

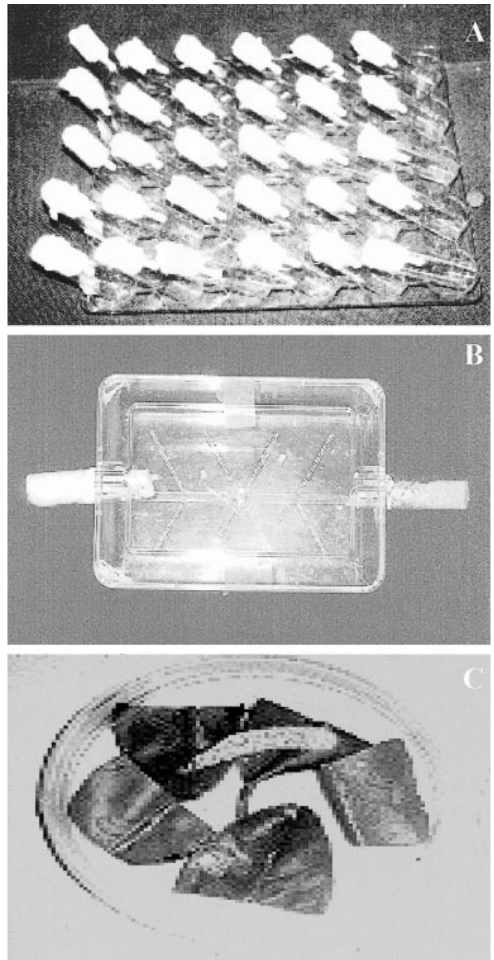

Figure 1.—Set-up for rearing spiders. (A). On the combination diet. (B). On adults of *Drosophila*. (C). On larvae of the citrus leafminer.

METHODS

Comparison of artificial diets.—The three different artificial diets evaluated with respect to the survival of *H. velox* were soybean liquid (non-dairy beverage, Edensoy™ Eden Foods Inc.), milk + egg yolk mixture (100 ml homogenized whole milk + 1 fresh chicken egg yolk), and their combination(1:1 soybean and milk + egg yolk mixture). One ml of green food color (McCormick™) was added to each diet to serve as an indicator of whether the spiders fed on the liquid diet since the color of their abdomen changes depending on the color of the food they consumed. The nutritional composition for each diet is shown in Table 1. A single first instar spiderling of *H. velox* was placed in a glass vial (15 mm diameter × 60 mm long) (Fig. 1A). The mouth of the vial was closed with a cotton swab saturated with the liquid diet. A one-inch long stick was impaled in the swab with the end pointing to the interior of the vial. The spider perched on the stick as it fed on the diet. The diet was replaced with fresh ingredients on a cotton swab every two days. The treatments for each artificial diet were replicated three times with 20 spiderlings per replication. All vials were kept in an incubator at 27 °C, 80% RH and a L:D 12:12 photoperiod. Spider mortality and molting were recorded every two days for 10 wk. The rate of development and growth in the different artificial diets was compared using one-way analysis of variance (ANOVA) (SAS institute 1989).

Nature/sources of artificial and natural

Table 1.—Nutritional composition of the different diets based on the manufacturers' nutritional analyses per 100 ml.

Nutrient composition	Milk + egg yolk	Soybean	Combination diet
Total fat	3.04 g	1.30 g	4.34 g
Saturated fat	1.30 g	0.0 g	1.3 g
Cholesterol	97.83 mg	0.0 mg	97.83 mg
Sodium	82.61 mg	39.13 mg	121.74 mg
Total carbohydrates	6.09 g	10.87 g	17.04 g
Sugars	5.22 g	6.52 g	12.99 g
Protein	6.04 g	2.61 g	8.65 g
Potassium	0.0 mg	126.09 mg	126.09 mg
Vitamin A	348.00 IU	0.0 IU	348 IU
Thiamin (B1)	0.0 mg	0.05 mg	0.05 mg
Riboflavin (B2)	0.0 mg	0.03 mg	0.03 mg
Niacin (B3)	0.0 mg	0.52 mg	0.52 mg
Pantothenic acid (B5)	0.0 mg	0.35 mg	0.35 mg
Pyridoxine hydrochloride (B6)	0.0 mg	0.05 mg	0.05 mg
Folate (B9)	0.0 mg	0.02 mg	0.02 mg
Vitamin C	0.52 mg	0.0 mg	0.52 mg
Vitamin D	43.48 IU	0.0 IU	43.48 IU
Biotin (Vitamin H)	0.0	0.0003 g	0.003 g
Calcium	0.14 g	0.03 g	0.17 g
Iron	0.31 mg	0.31 mg	0.62 mg
Phosphorus	0.11 g	0.04 g	0.15 g
Magnesium	0.0 mg	17.4 mg	17.4 mg
Zinc	0.0 mg	0.26 mg	0.26 mg

diets.—The composition of the artificial diet for rearing of spider colonies was similar to the combination diet (Table 1) to which 5 ml honey was added. The natural diets consisted of either adults of the fruit fly, *Drosophila melanogaster* Meigen 1830, or larvae of the citrus leafminer, *Phyllocnistis citrella* Stainton 1856. The fruit flies were mass reared in the laboratory at 25–27 °C and 70–80% RH. The initial population of fruit flies was obtained by exposing over-ripe bananas in a glass jar. The

Table 2.—Percentages of survival of *Hibana velox* during 10 weeks on three different artificial diets under laboratory conditions at 27° C and 80% RH. Means followed by the same letters in the same row are not significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test.

	Artificial diets		
Week	Milk + yolk	Soybean	Combination
1	86.67 a	95.53 a	95.57 a
2	86.63 a	95.53 a	95.57 a
3	68.87 b	93.30 a	95.57 a
4	60.00 b	86.70 a	88.87 a
5	46.67 b	77.77 a	86.67 a
6	39.97 b	73.33 a	66.67 a
7	26.67 bc	53.33 ab	57.77 a
8	22.33 b	51.10 a	51.10 a
9	17.80 b	42.20 a	42.23 a
10	17.80 b	42.20 a	42.23 a

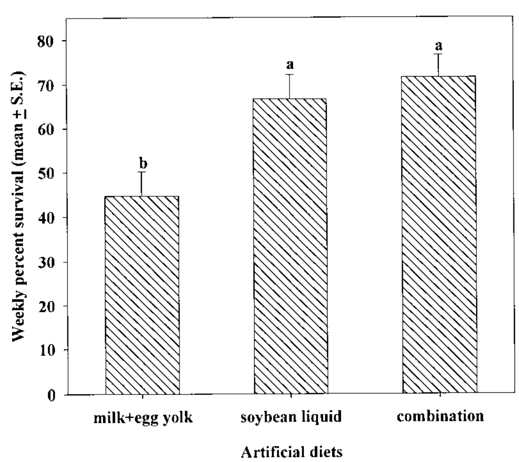

Figure 2.—Mean weekly survival of *Hibana velox* reared on different artificial diets. Bars with the same letters are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$).

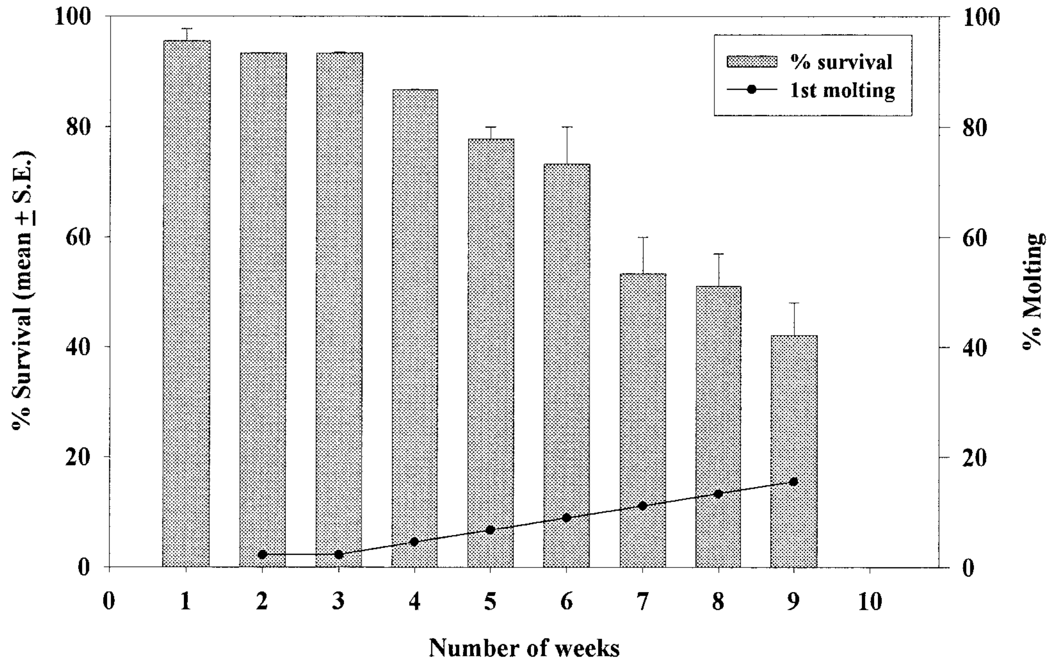

Figure 3.—Weekly percentages of survival and molting of *Hibana velox* reared on soybean liquid diet.

fruit fly adults trapped in the jar were reared using the banana medium described by Yoon (1985), with some modifications. Approximately 10 ml of the medium were poured from a sterilized beaker into each sterilized glass vial (15 mm diameter × 60 mm long). After the medium cooled, a sterilized strip of filter paper (1 cm × 5 cm) was inserted into each vial. The mouth of the vial was plugged with a sterilized cotton ball. The vials were stored for a day at 20 °C before use or stored at 4 °C until needed. Adult fruit flies from the initial population were immobilized by placing them in a freezer (~0 °C) for 30–40 s and transferred to an empty glass jar. Ether was used for a longer period of immobilization. Next, five males and five females were transferred to each glass vial containing banana medium. The fruit fly cultures were kept in an incubator at 27 °C and 80% RH. Adults from the succeeding cultures were mass reared. To avoid inbreeding, adult fruit flies from different stock cultures were mixed for re-culturing. A 1 wk-old fruit fly culture was utilized for spider rearing. This provided a continous supply for the spider in the rearing cage for 3–4 wk.

Citrus leafminer larvae were collected from an unsprayed lime orchard or from a greenhouse culture on lime shoots.

Test spiders.—Egg sacs of *C. inclusum*, *H. velox* and *T. volutus* were collected in the field, brought to the laboratory and maintained in an incubator at 27 °C and 80% RH until spiderling emergence. Egg sacs were identified based on the description by Amalin et al. (1999). First instar spiderlings were used in the experiment. Voucher specimens are deposited at the Tropical Research and Education Center (TREC), Entomology Division at Homestead, Florida.

Experimental protocol.—Three different containers were used for artificial and natural rearing. These rearing containers were used based on the preliminary trial we conducted on different rearing containers for each diet. They were selected for ease of handling of the spiders with minimal injury and disturbance, and also for speed in replacing the diet. The cage size might have an effect on the feeding behavior of the spiders, but this was not considered in this study. The spiders fed with artificial diet were placed in glass vials (15 mm diameter × 60 mm long) (Fig. 1A) as explained in the experiment on the comparison of artificial diets. To rear the spiders on *D.*

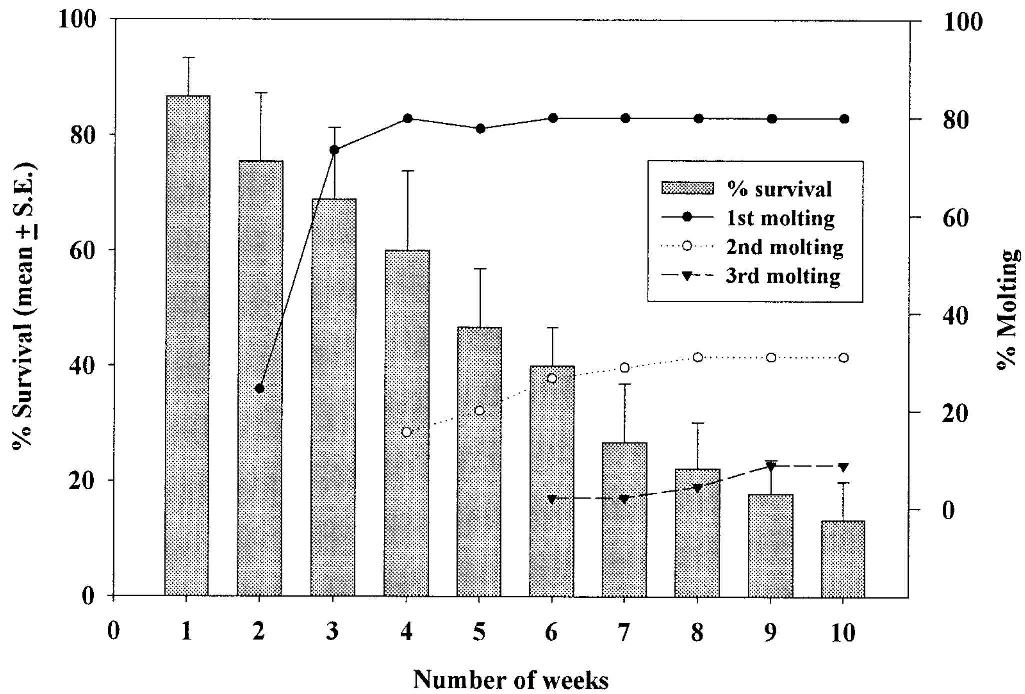

Figure 4.—Weekly percentages of survival and molting of *Hibana velox* reared on milk + yolk diet.

melanogaster, newly emerged spiderlings were placed individually in a translucent plastic box (70 cm high × 70 cm long × 20 cm wide) (Fig. 1B) with two circular openings (2 cm diameter) in the opposite sides. A 30 ml vial containing 10 ml of water was plugged with cotton and inserted into the one opening of the box. A glass vial containing a 1 wk-old culture of *D. melanogaster* adults on banana medium was introduced through the second circular opening. The spiders fed with 10 second instar *P. citrella* larvae were placed with these prey inside a plastic petri dish (10 cm in diameter × 1 cm high) lined with moistened filter paper (Fig. 1C).

Thirty spiders of each species were reared from egg to maturity on the different diets. All spiders were maintained in an incubator at 27 °C and 80% RH with a L:D 12:12 photoperiod. The artificial diet and *P. citrella* larvae were replaced every 2 days, whereas *D. melanogaster* cultures were checked every 2 wk and replaced as needed. The survival and the developmental rates of the three sac spiders reared on artificial and natural diets were compared using Duncan Multiple Range Test (SAS Institute 1989).

RESULTS

Comparison of artificial diets.—Spiders raised on milk + egg yolk diet had a significantly lower weekly percentage survival than those reared on soybean liquid diet and the combination diet (Fig. 2). Table 2 shows the percentage spider survival weekly for a period of 10 wk. During wk 1 and 2, percentages of spider survival did not differ significantly among the three artificial diets. From wk 3 to wk 10, the percentages of spider survival were significantly higher for soybean liquid and combination diets than the milk + egg yolk mixture diet. In wk 7, percentages of spider survival on soybean liquid did not differ significantly from that of milk + egg yolk and combination diets. However, percentage survival was significantly higher on combination diet than on milk + egg yolk diet.

The developmental growth of *H. velox* reared on the different artificial diets was recorded based on weekly survival and percentages of molting (Figs. 3–5). The growth of spiders differed on the various artificial diets. Only 2% of the spiders raised on soybean liquid diet underwent one single molt during

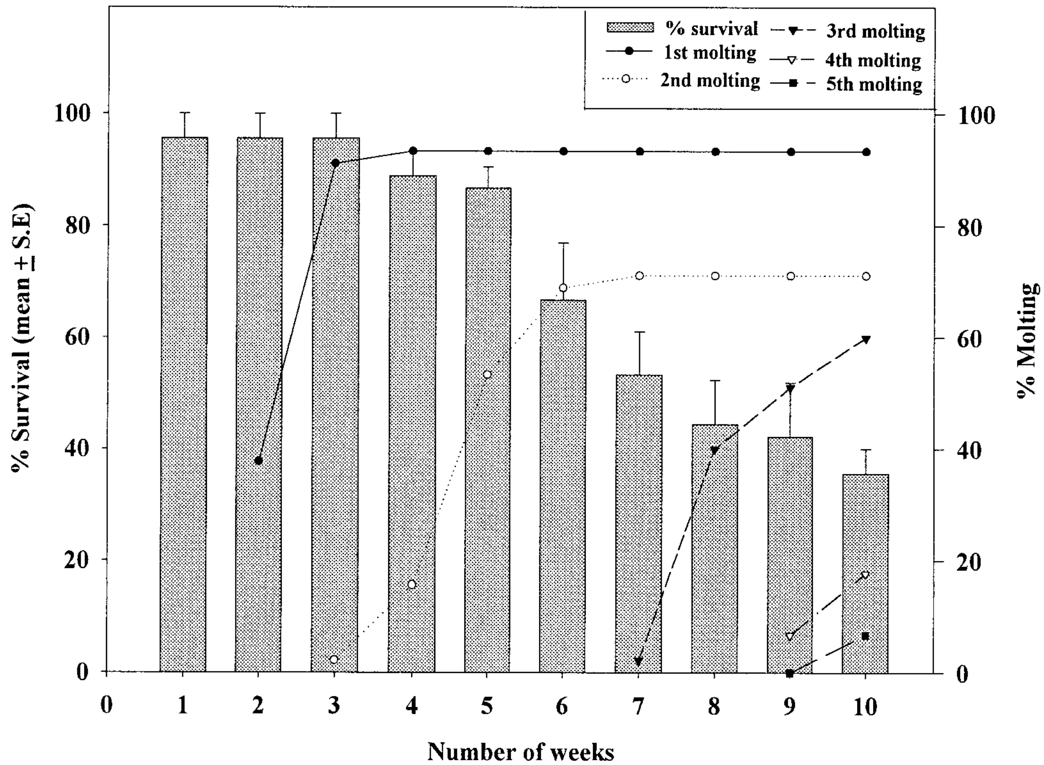

Figure 5.—Weekly percentages of survival and molting of *Hibana velox* reared on combination diet.

the second and third weeks of rearing (Fig. 3). The peak of molting was observed during week 9. Percentage survival of *H. velox* on soybean liquid diet was relatively high. More than 90% survived from week 1 to week 3 and 80% from from week 4 to week 6. During weeks 7 to 9, percentage survival decreased to less than 50% and by week 10 all of the spiders raised on this diet died (Fig. 3).

Spiders reared on milk + egg yolk mixture and combination diets underwent more molts than those reared on soybean liquid diet (Figs. 4, 5). Spiders raised on milk + egg yolk diet molted three times (Fig. 4). A mean of 34.4% of the total spiders molted in week 2 and the percent that molted increased as the rearing progressed. The frequency of first molts peaked in week 4 and remained level. Eighty percent of the surviving spiders molted at least once. Almost 50% of the surviving spiders underwent a second molt between weeks 4 and 10, third molts started on week 6 until week 10. Percentage survival drastically decreased from week 1 to week 10, from 85% to 9%. Spiders raised on the combination diet underwent as many as five molts (Fig. 5). First molts started during week 2, with a mean of almost 40%, and reached 93.3% by week 4. Second molts started during week 3, which was a week earlier than on milk + egg yolk diet; however, the percentage of second molts rose during week 4 and peaked in week 6. Third molts peaked during week 10. However, very few spiders reared on combination diet underwent the fourth and fifth molts. The trend of the percentage survival of spiders reared on the combination diet was similar to that on the soybean liquid diet except on week 10 in which almost 40% were still surviving.

Comparison of artificial and natural diets.—The developmental stages and percentages of survival for each developmental stages of the three sac spider species reared on artificial and natural diets are shown in Figs. 6–8. On the combination diet, all three species were able to develop into the adult stage (Fig. 6), after the sixth and seventh molts. In general, percentages of survival of *H. velox* were relatively higher than those of *C. inclusum* and *T. volutus* in all developmental stages on

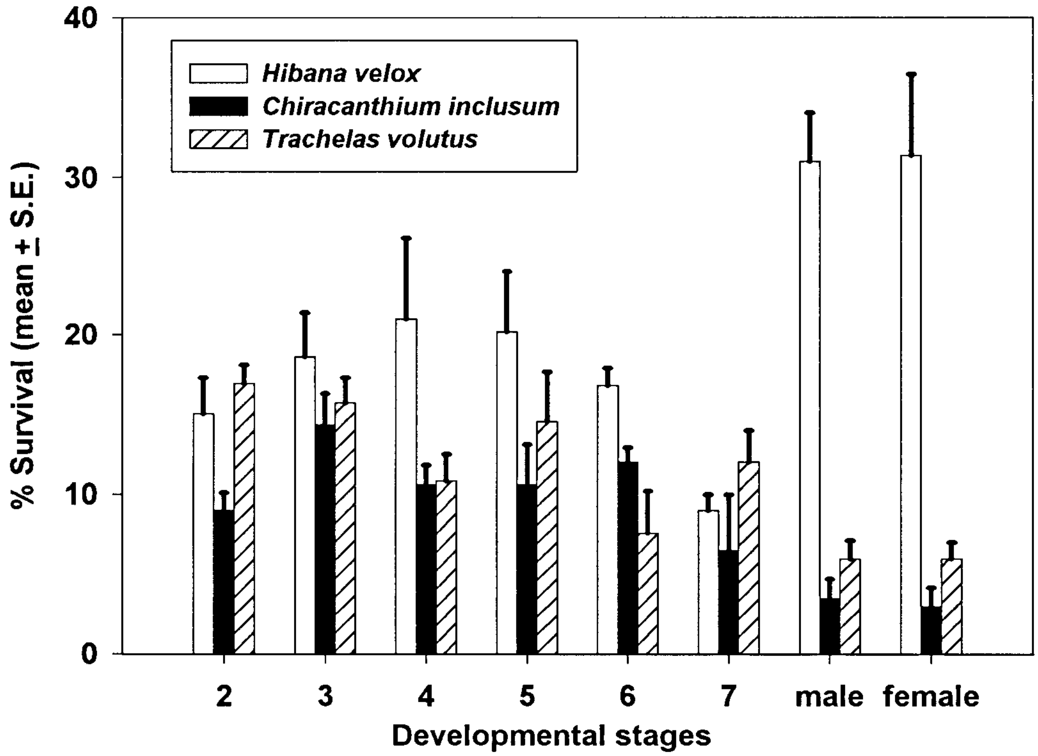

Figure 6.—Survival of developmental stages of *Chiracanthium inclusum*, *Hibana velox*, and *Trachelas volutus* reared on combination diet.

the combination diet. Moreover, percentage survival to adulthood was higher for *H. velox* than for *C. inclusum* and *T. volutus*. From the surviving spiders in the sixth and seventh molt stages, 31% and 32% of *H. velox* developed into male and female adults, respectively. Survival was less than 10% for *C. inclusum* and *T. volutus*. Females that matured on combination diet and were fertilized in captivity produced one to three egg masses. Oviposition took place 2–7 days after mating for all three species. The number of eggs laid by female *H. velox* ranges from 96–120 with an average of 110. The number of eggs per egg mass of *C. inclusum* reared in the laboratory varied from 36–86 with an average of 57. Edwards (1958) reported 112 eggs in a single egg mass and Peck & Whitcomb (1970) reported a range of 17–86 eggs per egg mass. *Trachelas volutus* produced 47–66 per egg mass with an average of 56.

The three species of sac spiders reared on *Drosophila* were able to develop into the adult stage (Fig. 7). In general, percentage survival of *T. volutus* was relatively higher than those of *H. velox* and *C. inclusum* for the immature stages. However, *C. inclusum* and *H. velox* had higher percentages survival to the adult stage. Less than 10% from the seventh and eighth molt stages survived into male and female adults for *T. volutus*. For *C. inclusum*, 30% and 38% from the seventh and eighth molt stages developed into male and female adults, respectively. For *H. velox*, 17% developed into male and 12% into female adults.

In general, percentage survival of *T. volutus* was relatively higher than those of *H. velox* and *C. inclusum* when reared on *P. citrella*. *Trachelas volutus* and *C. inclusum* successfully developed into the adult stage but *H. velox* did not (Fig. 8). This finding suggests that *P. citrella* is deficient in one or more nutrients required by *H. velox*. However, the consumption of *P. citrella* by immature *H. velox* was relatively higher than by *C. inclusum* and *T. volutus*.

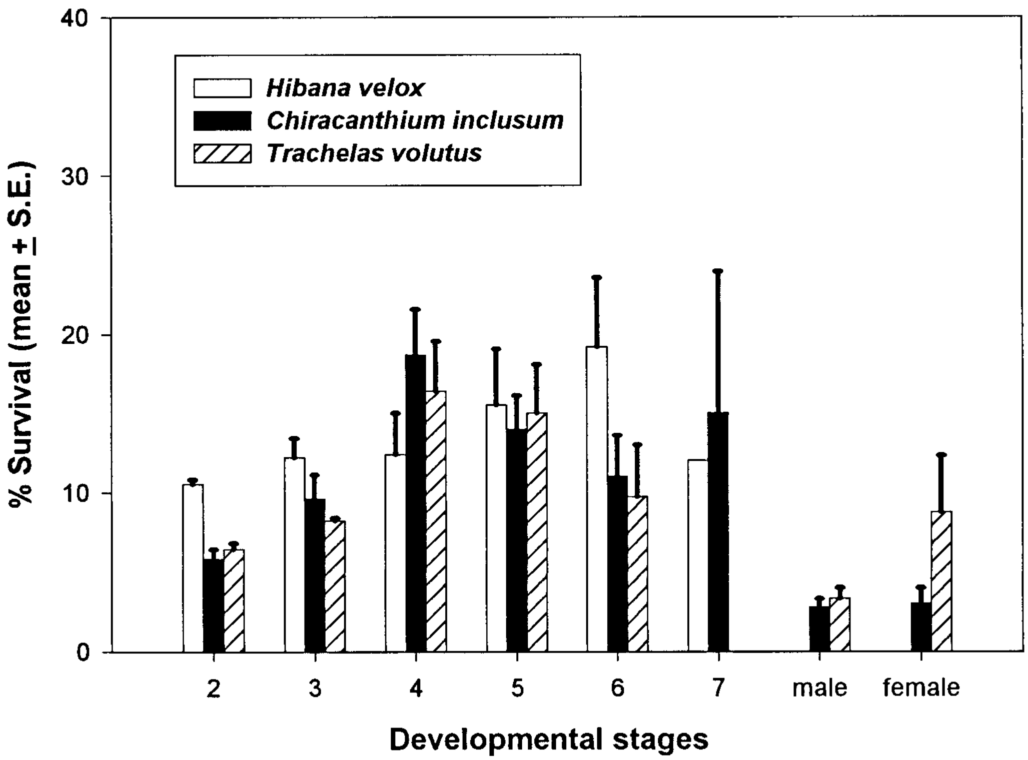

Figure 7.—Survival of developmental stages of *Chiracanthium inclusum, Hibana velox*, and *Trachelas volutus* reared on adults of *Drosophila*.

DISCUSSION

Each single diet has an important nutrient for the growth and survival of spiders under laboratory conditions. For instance, on soybean liquid and combination diets the following nutrients are available in relatively higher amounts: carbohydrates, sugar, potassium, magnesium, and zinc. Among these nutrients, carbohydrates are known to be the major energy source important for survival or longevity of any arthropod species, whereas the minerals potassium, magnesium, and zinc are necessary for optimal growth (Singh 1984). Vitamin B-complex is also required in artificial diets and is available in soybean liquid but absent in milk + egg yolk diet. This finding suggests that if enough carbohydrates. and possibly the other nutrients mentioned above are available, mortality at an early stage of spider development will be avoided. However, results from our previous experiment (Amalin et al. 1999) revealed that the development of spiders on soybean liquid was delayed but progressed normally on milk + egg yolk diet. The main nutrient that is available in milk + egg yolk diet, which is absent in soybean liquid, is cholesterol. Cholesterol is a common sterol and a precursor of ecdysone, the molting hormone (Foelix 1982; Singh 1984). This may explain the delayed development of spiders on soybean diet. Other nutrients available in relatively higher amounts in milk + egg yolk diet are total fat, saturated fat, sodium, protein, Vitamin A, Vitamin D, calcium, and phosphorous. These nutrients may also contribute to the complete development of spiders on milk + egg yolk diet. According to House (1961) an artificial diet should contain a balance of proteins, carbohydrates, lipids, and vitamins for normal growth, development, reproduction and other life processes. All of these important nutrients are available in the combination diet with more concentrated values (Table 1), which probably explains the higher percent survival and normal development of spiders on the combination diet than on the soybean and milk + egg yolk diets. The completion of development of the three

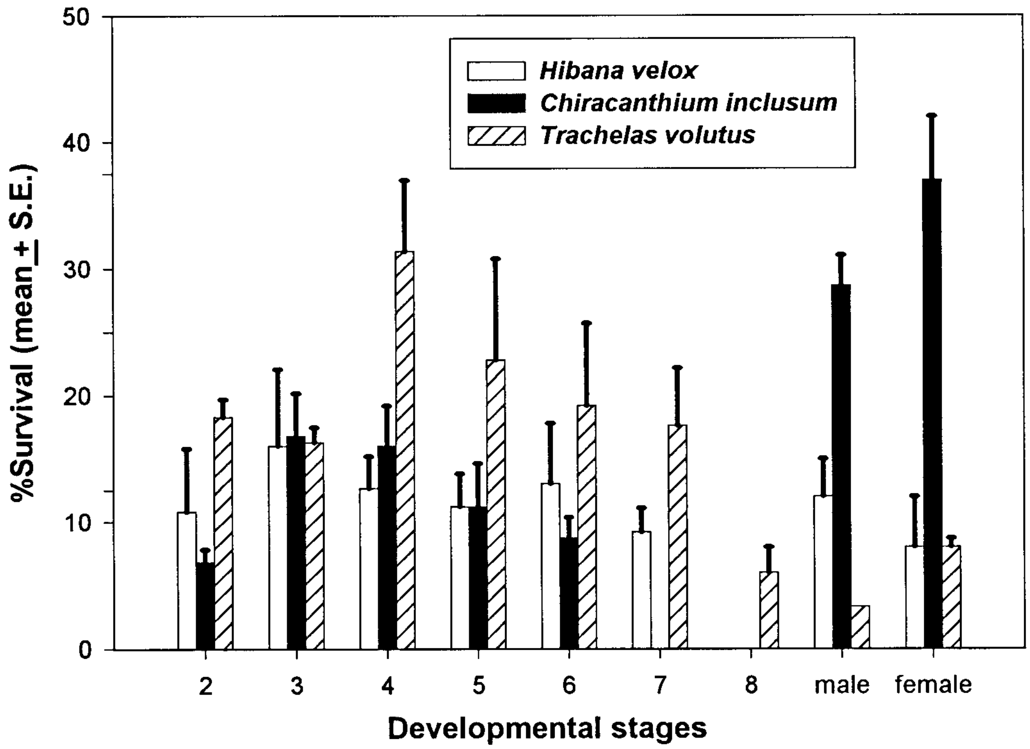

Figure 8.—Survival of developmental stages of *Chiracanthium inclusum*, *Hibana velox*, and *Trachelas volutus* reared on larvae of citrus leafminer.

species of sac spiders on the combination diet suggests that they are also nectar feeders as reported by Taylor & Foster (1996). This further suggests that the combination diet provided more complete nutrional or dietary requirements for sac spiders. Nevertheless, different species of spiders even under the same guild or group could have different requirements of the proportion of all the nutrients pertinent to survival and development. This might be one reason why there was a higher percentage survival of *H. velox* fed with combination diet than *C. inclusum* and *T. volutus*. Thus, we recommend that different proportions of the nutrients of the combination diet should be tried to determine the best proportion of each one for the survival and development of these three species of sac spiders. Behavioral and ecological differences among these three species of sac spiders should not be ruled out as possible reasons for differences in percentage survival; however, any such differences were not observed in this particular study. Of the natural diets tested, *Drosophila* provided a suitable diet for the three species of spiders particularly for *H. velox* and *C. inclusum*; whereas, citrus leafminer seems to be less suitable as diet of the spiders under laboratory conditions.

Results from this experiment reveal that an artificial diet is adequate for these spiders under laboratory conditions. Attempts towards the mass rearing of these spiders using artificial diets should be pursued. Clearly the proportions of the various ingredients in combination diet must be evaluated to optimize spider survival and reproduction. Advancements in mass-rearing spiders on artificial diets may enable their use in agriculture for augmentation of field populations.

ACKNOWLEDGMENTS

We thank Drs. Waldemar Klassen and Norman Leppla for review of the manuscript. We also thank Michelle Codallo, Jose Alegria, and Ivan Toledo for their help in rearing the spiders. Florida Agricultural Experiment Station Journal Series No. R-07222.

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Manuscript received 20 May 2000, revised 1 December 2000.