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SHORT COMMUNICATION

Notes on the life history traits of *Rhopalurus rochai* (Scorpiones, Buthidae) under different feeding regimes

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Abstract. *Rhopalurus rochai* (Borelli 1910) is a very common scorpion species found in the semiarid areas of Pernambuco State, Brazil. This work describes the life history traits of 1st instar *R. rochai* such as litter size, development time, dispersal, and survivorship. The development of 2nd instar juveniles under different feeding regimens was also investigated to determine the effect of food and body mass on intermolt period and number of ecdyses. Field-collected females displaying an enlarged mesosoma were observed daily in the laboratory to obtain newborns that were used to assess events in the 1st instar. Females gave birth on average to 35.8 young (range = 23–55). The duration of the 1st instar (from eclosion to ecdysis) ranged from 7 to 10 days (n = 179). Dispersal started as early as one day following ecdysis and lasted up to 9 days post-molt. All starved juveniles died between days 11 and 30 of the 2nd instar. Increasing food ingestion did not enhance the probability of molting, but decreased risk of mortality and increased the time to the second molt. The relationship between the weight changes during feeding experiments suggests that the threshold weight for molt is 34.3 mg. Together these results suggest that developmental periods for *R. rochai* are slightly greater than those recorded for other buthid genera. These results indicate that there may be inherent physiological costs associated with rapidly increasing mass that may strongly impact foraging strategy.

Keywords: Development time, dispersal time, scorpion, starvation, molt

The genus *Rhopalurus* (Thorell 1876) belongs to the family Buthidae which, along with Liochelidae, Euscorpiidae, Chactidae, and Bothriuridae, forms the Brazilian scorpiofauna (Soleglad & Fet 2003). Nine species of this genus (Lenarducci et al. 2005) are known in Brazil and occur in the Central and Northeast regions within the *cerrado* (Brazilian savannas) and *caatinga* (Lourenço 1986). Despite numerous studies on the taxonomy and biogeography of *Rhopalurus* (Mello-Leitão 1945; Lourenço 1986; Lourenço & Pinto-da-Rocha 1997; Manzanilla & De Sousa 2003; Lenarducci et al. 2005), there is little information on its reproduction, postembryonic development, and nutrition.

The reproductive fitness of females and individual life span are important factors in establishing the population size of a species. The number of offspring produced by a female is one measure of reproductive fitness, and there may be a positive or negative correlation between litter size and female body mass (Lourenço et al. 1996). The duration of postembryonic development is a key factor in determining generation time, with shorter durations lowering the risk of mortality before reaching reproductive maturity and enhancing individual fitness. On the one hand, this type of growth is frequently associated with higher feeding and food assimilation rates in conjunction with a more efficient conversion of food into biomass (Danner & Joern 2003; Branson 2004; McPeek 2004; Stoks et al. 2005). On the other hand, longer development cycles are generally associated with low mass-accumulation rates and higher reproductive costs, such as delayed sexual maturation (Stearns & Koella 1986; Higgins & Rankin 1996; Higgins 2000) and a higher risk of mortality before reaching adulthood (Higgins & Rankin 1996).

Food availability in the field is influenced by seasonal variation, and food shortage is a constraint that terrestrial invertebrates often have to contend with. Such a shortage is likely to affect survival (Iida & Fujisaki 2007) and reproductive output (Bauerfeind & Fischer 2005), particularly in arthropods with long life cycles. Being animals with an extended life span, range = 6–83 months (Polis & Sissom 1990), scorpions will suffer the impact of environmental variation in food availability. These animals are widely distributed throughout the world, but nutritional bases for scorpion growth and development are usually under-investigated. Even the baseline data on their nutritional needs for survival or molting are lacking.

We describe in this paper some observations about the litter size, dispersal time, and 1st instar duration and survival of *R. rochai* and compare this information to available data on other genera of Buthidae. Considering that nutrition is an important aspect in determining growth and development in an organism, the effects of body mass and molting for individuals during 2nd instar development are also presented.

METHODS

Females of *R. rochai* (n = 5) were collected in Limoeiro municipality in the Agreste Mesoregion and Medio Capibaribe Microregion of Pernambuco State, Brazil (area = 277.54 km^2; 07°52′29″ S, 35°27′01″ W; 138 m elev.), 90.9 km from the state capital, Recife. The climate is wet tropical with dry summers. The rainy season starts in January/February and ends in September, but may last until October. The specimens were collected under accumulations of rocks from soil preparation for corn and bean cultivation or from pastures at sites with rock outcrops and low-height deciduous and semi-deciduous plants typical of the agreste (Beltrão et al. 2005). Pregnant females (displaying a dilated mesosoma) were kept in individual plastic containers (8.5 cm diameter × 7.8 cm high) with an assay tube containing cotton soaked in water and a cardboard piece for shelter. They were fed adult *Periplaneta americana* (Linnaeus 1758) once every 15 days. In the laboratory, the temperature was maintained at environmental conditions of 28° ± 3° C with 12L:12D photoperiod. Observations were made daily to record the period in which the young were born

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Table 1.—Litter size, first instar duration, survivorship and dispersal of *Rhopalurus rochai* offspring from wild-caught pregnant females maintained in the laboratory.

Number of individuals/ litter	Interval between birth and 1st molt (days)	Dispersal time (days)	Survival ratio of 1st and 2 nd molts (%)
34	9	2–9	100
29	8	3–5	100
55	7	2–8	100
23	10	1–6	100
38	8	2–4	100

and to determine litter size, interval between birth and 1st ecdysis, dispersal time and number of individuals that molted into the 2nd instar. Because the offspring clustered on the female dorsum making an exact count very difficult, litter size was considered as the total number of individuals recorded after dispersal. Every living and dead individual was counted except for those that were cannibalized by the female.

The relation between feeding and molting was studied in a group of 38 juveniles in the 2nd instar that were obtained from the litters of two females. Just after dispersal, scorpions were weighed and divided into three groups: not fed (n = 10); fed once/week (n = 13); fed three times/week (n = 15). In each group, scorpions were weighed before and after feeding, including those that did not feed. One prey item (1st instar nymph of *P. americana*, approximately 5.50 ± 0.90 mg) was fed to each juvenile each time. The difference between final mass and initial mass was used to determine the influence of feeding on molting success, survival and intermolt period in these groups. Juveniles from the unfed group were weighed at the beginning of the experiment and after death.

The biomass growth of scorpions fed once and three times per week was compared using a Student's t test and the mortality of the two groups was evaluated using a χ^2 test. Correlations between initial biomass and intermolt period, as well as between initial biomass and life span of the food-deprived individuals, were tested using Spearman correlation because the data were not normally distributed. The normality and variance homogeneity of the data were tested using Shapiro-Wilk and Levene tests, respectively. All tests were conducted with STATISTICA 7 software with a significance level 0.05. Voucher specimens are deposited at the Entomological Collection of the Laboratory of Terrestrial Invertebrates, Universidade Federal de Pernambuco, Brazil. Most specimens were alive at the time this manuscript was completed, and they will be deposited at the same place as soon as they die.

RESULTS

Litter size.—The average number of recorded offspring in *R. rochia* was 35.8 ± 12.11 individuals (range = 23–55) (Table 1). Cannibalism by the female was recorded only at the moment of birth in four out of the five observations. It was not possible to determine the number of cannibalized stillborns due to the difficulty of viewing the act once the offspring were hidden by the pedipalps. However, it was possible to observe that the cannibalized offspring showed a highly softened, sometimes wrinkled tegument and small size when compared to those on the dorsum.

First instar duration and dispersal time.—Litter size, 1st instar duration, survival, and dispersal of *R. rochai* offspring are shown in Table 1. The first molt was assessed in 179 individuals from different litters and occurred on average 9 days after birth (range = 7–10 days) and occurred on the same day in all individuals from the same brood. Dispersal started 1–3 days after the 1st molt and was completed 4–9 days after that. Occasionally, juveniles were observed to climb down from the mother's back. No dead scorpions were found during the 1st instar period, and all juveniles reached the first molt.

Effects of starvation and feeding on body mass and molting.—Mean mass variation, intermolt period, and molt frequency of *R. rochai* under different feeding treatments and mass variation during starvation are shown in Table 2. Overall mean body mass just after juveniles climbed down from their mother's dorsum was on average 16.43 ± 1.28 mg (ranging = 12.3–18.7 mg). The initial biomass was not correlated with total life span in food-deprived animals (r = 0.18, P = 0.61) (Fig. 1A). Among these individuals, none (n = 10) reached the 2nd molt, with mortality occurring between 11 and 30 days after the 1st ecdysis. The biomass lost during food deprivation was on average 2.8 mg (range = 2–4 mg) with the lowest mass of 10.5 mg and highest 14.7 mg. No relationship was observed between initial biomass and weight loss. Feeding more often did not influence molting success but did extend the intermolt period (fed once per week: r = −0.34, P = 0.36, and fed three times per week: r = 0.59, P = 0.04) (Fig. 1B, C). The scorpions fed three times per week showed a greater biomass increase (53.0 ± 13.2 mg) when compared to those fed only once (45.0 ± 4.1 mg), though this difference was not significant (t = −1.73, df = 16, P = 0.10) (Fig. 1D). In the group fed once per week, the minimum weight for molting was 39.6 mg and the maximum was 51.8 mg, while in the other group the minimum was 34.3 mg and the maximum was 79.9 mg.

Mortality was 30.8% (n = 4/13) among those fed once per week and 40.0% (n = 6/15) among those fed three times per week. No significant difference was found in mortality between groups fed once or three times per week (χ^2 = 0.18; df =1; P = 0.67). In the former group, 100% of the deaths occurred during intermolt, while in the latter 20% were recorded during ecdysis. The mean intermolt period increased 22.48 days in the group fed more often, varying from 169.77 ± 28.97 days in the group fed only once per week to 192.25 ± 44.60 days in the group fed three times per week (Table 2).

DISCUSSION

Most reproductive traits, such as litter size, 1st instar duration, dispersal time, and survivorship show a large variation among scorpion species (Polis & Sissom 1990). Average litter size of *R. rochai* recorded in this study (approximately 36 young) is one of the largest brood sizes yet described for buthid scorpions. Females from most buthid species give birth to fewer than 27 young (see summary by Lourenço 2002). A previous study (Matthiesen in Polis & Sissom 1990) has described litter size having range = 28–49 individuals in *R. rochai*. The difference in the number of offspring relative to our findings (23–55 young) may indicate adaptation to microvariation in

Table 2.—Mass variation, intermolt period and molt frequency of *Rophalurus rochai* during starvation and different feeding patterns. Final mass for starved juveniles was considered by weighing individuals after death. For other groups, final mass = offspring mass before molt or at death during molt.

Feeding regime	Initial Mass (mg)	Final Mass (mg)	Mass lost during molt (mg)	Molt frequency (%)	Molt interval (days)
Starvation (n = 10)	15.04 ± 1.36	12.60 ± 1.28	-	-	-
Feeding once (n = 13)	17.00 ± 1.04	45.01 ± 4.14	7.7 ± 4.36	69.2	169.77 ± 28.97
Feeding three times (n = 15)	17.03 ± 0.99	53.04 ± 13.56	3.44 ± 3.46	60.0	192.25 ± 44.60

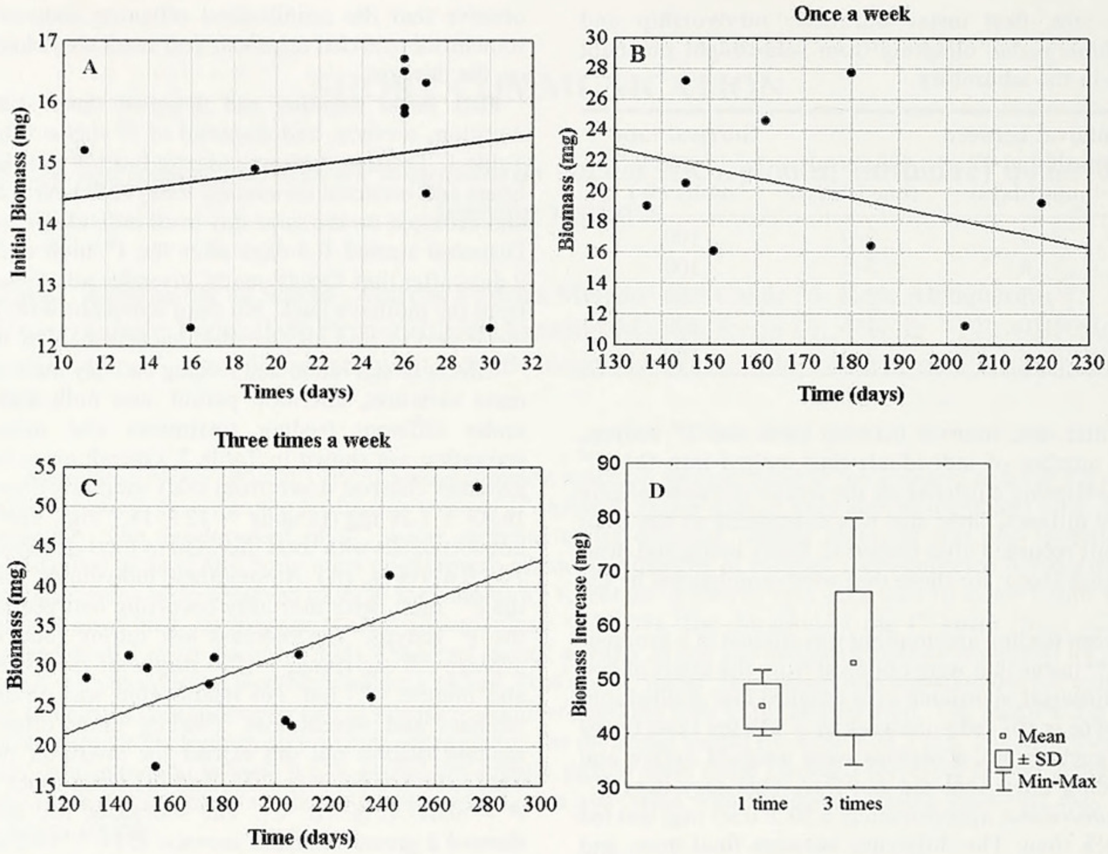

Figure 1.—Aspects of post-embryonic development of 2nd instar *Rhopalurus rochai*. A. Correlation between initial biomass and total life span in food deprived juveniles. B, C. Intermolt period as a function of feeding frequency: B. Once a week; C. Three times/week. D. Relative biomass increase in the scorpions fed once or three times a week.

the environment faced by females from the different populations used in the two studies and also may reflect genetic differences among populations as suggested by Brown & Formanowicz (1995). The number of 2nd instars (just after dispersal) in broods of *R. rochai* also represented a wide range (23–55). Such variation may be partly influenced by differences in female mass or cannibalism, as observed by Warburg & Elias (1998) for the large number of 1st instars in the litter size (17–33) recorded in *Scorpio maurus fuscus*. Among female scorpions, cannibalism of newborns is a normal behavior that makes estimation of offspring numbers more difficult (Polis 1980). In this study, cannibalism was observed during parturition in 80% of pregnant females.

Like all scorpions (Williams 1969; Lourenço 1979a, b, 1991; Polis & Sissom 1990), females of *R. rochai* provide maternal care to offspring for several days after giving birth to live young. During this 1st instar phase, the young remain on their mother's back without feeding, and this may be considered a continuation and extension of embryological development (Farley 2005). In general, the duration of this period ranges from 5 to 25 days (Lourenço 2002). In this context, *R. rochai* showed a short 1st instar phase (8 days) which was similar to *Centruroides gracilis* (Latreille 1804) (8 days) (Francke & Jones 1982) and *Centruroides exilicauda* (Wood 1863) (7 days) (Brown 2004) and half as long as *Tityus trivittatus* Kraepelin 1898 at 16 days (Toscano-Gadea 2004).

Although feeding success can be considered a measure of individual fitness, the rate of food intake among juvenile scorpions under natural conditions is still largely unknown. Food supplementation in *R. rochai* did not increase the chances of molting, but significatively extended the intermolt period. In addition a tendency toward increased mortality was also observed in this group. Similarly, *Nephila clavipes* (L. 1767) spiders were more likely to die at or immediately before the next molting cycle after getting larger quantities of food, indicating a possible physiological cost of rapidly increasing mass (Higgins & Rankin 2001). Therefore, when prey is abundant, it may represent a real cost to the development of opportunistic feeders such as spiders and scorpions.

The increasing mortality risk due to intake of a large number of prey is known in other invertebrates. Survival of *Aedes aegypti* larvae was reported to be lower at the highest feeding levels when immature specimens were reared in the laboratory (Arrivillaga & Barrera 2004). Scorpions are predators of small arthropods and may feed infrequently during their life, which may last many years (Lighton et al. 2001). Hence the ability of immatures to survive at low feeding rates is a considerable adaptation for facing periods of low prey availability.

The 2nd instar duration for *R. rochai* fed weekly was on average 170 days. Starved individuals in the same instar survived 30 days maximum (initial weight = 16.43 ± 1.28 mg), indicating the low resistance of these invertebrates to lack of food. In contrast, according to Tanaka & Itô (1982) and Rickers & Scheu (2005), spiders are tolerant to starvation for a long period of time. In a common grasslands spider, *Pardosa palustris* (L. 1758), for instance, the second instar juveniles with the initial weight of 0.32 ± 0.07 mg survived 9.86 ± 2.28 days in starvation (Rickers & Scheu 2005). In the wolf spider, *P. astrigera* (L. Koch 1878), adult males and females could survive on average 28.8 ± 2.7 days and 54.4 ± 18.9 days, respectively, without any food (Tanaka & Itô 1982).

Relative to other developmental phases, the 2nd instar of *R. rochai* must be a critical period for growth because the previous instar juveniles do not feed and must expend all of their nutritional reserves for molting and survival. In the scorpion *Pandinus imperator* (C.L. Koch 1841), for instance, weight at birth is 443 mg and decreases to 381 mg after the first molt (Mahsberg 2001). Nutritional reserves at the start of the 2nd instar in *R. rochai* are likely to be the lowest of the entire life span and successful foraging is crucial to survival. Reduction in body weight due to starvation up to death was on average 13.3% of the starting weight. In other arthropods such as the spider *Pardosa palustris*, starving second instar juveniles with an initial weight of 0.32 ± 0.07 mg survived 9.86 ± 2.28 days (Rickers & Scheu 2005). Lower tolerance to starvation was described for the juvenile Chinese mitten-handed crab (*Eriocheir sinensis*) which survived over 70 days (initial weight = 4.01 mg) (Wen et al. 2006).

The physiological cost of food supplementation with a rapid increase in mass in *R. rochai* is unknown but appears to have a fundamental effect on population dynamics by prolonging the time for a new generation to be formed.

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