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Brood care and family cohesion in the tropical scorpion *Pandinus imperator* (Koch) (Scorpiones: Scorpionidae)

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Pandinus imperator is a forest dweller of tropical West Africa. In the field, I observed aggregations of up to 15 individuals. In the laboratory, mixed age groups of related and also unrelated animals lived jointly in terraria rarely showing within-group aggression or cannibalism.

Brood-caring behavior of the mother influenced growth rate and survival probability of the young. With birth, mothers became very aggressive.

To study family cohesion in *Pandinus*, experiments with family groups were conducted. Siblings aggregated around their mother. In choice experiments with two family groups, mothers were placed in enclosures that only the young were able to enter or to leave. Second instars significantly preferred the enclosure containing their own mother. Aggression among unrelated young of the same age was not observed.

Feeding experiments studied the possible advantages of long-lasting group living with regard to enhanced success in prey capture and its effect on growth of the young. Even groups of second instars were unable to subdue large prey on their own. Sibling groups with their mother removed suffered high mortality due to starvation and cannibalism compared to groups with mothers present. Here, young grew significantly faster: they shared the prey that only the mother was able to kill and dismember. *Pandinus imperator* has to be considered an intermediate subsocial scorpion.

1. Introduction

Only a few arachnid species exhibit social behavior (Buskirk 1981). In scorpions, 'social phases' are normally restricted to interactions during mating and the maternal care of offspring from birth to shortly after the first molt. There are, however, several reports of aggregations in scorpions in the field, consisting partly of unrelated and partly of related individuals. These observations, summarized by Polis & Lourenço (1986) suggest that living in a group may be an important feature of some scorpion species. The

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following study describes experiments on group behavior in *Pandinus imperator* (Koch) (Scorpionidae), a ground-dwelling scorpion inhabiting rain and gallery forests of tropical Africa. In *Pandinus*, group behavior appears to be more highly evolved than in most other scorpions.

2. Materials and methods

Specimens of *Pandinus imperator* were collected in a secondary forest in the Ivory Coast/West Africa. All young used for laboratory experiments were bred in captivity. The scorpions were individually paint-marked. They were kept at a relative humidity of at least 90% and a temperature of 23°C (night) to 26°C (day). For further details on breeding conditions, see Krapf (1988).

Aggregation experiments with two (unrelated) family groups of *Pandinus* (second instars and their mother) were performed in an arena (1 m^2) with four shelters (19×10×3 cm), one in each corner. Before each trial, the soil in the arena was mixed and shelters were interchanged. Late in the afternoon, the scorpions were released into the center of the arena. They were active only at night. By sunrise, at the latest, all were hidden in a shelter. To enclose an adult female, a plastic container of 20×20×7 cm was turned over each shelter. Small horizontal slits in the container walls allowed young scorpions to enter such shelters, but prevented the female from leaving them. The females were randomly distributed into the enclosures. The scorpions found under each shelter were counted about 24 hours after release (specimens were never found outside a shelter). The experiments were repeated 12 to 14 times, and the data pooled thereafter (the experimental conditions were always the same). For evaluation of data, 'shelter 1' always referred to the shelter where the mother was found. The other shelters (2, 3, and 4) were ranked in descending order of the total number of young which were counted in each during the entire experiment. The observed distribution of animals was tested against a uniform distribution.

For feeding experiments, the second instars of a female were randomly allotted to one of the following groups:

a) mother present; live prey offered,
b) mother absent; live prey, and
c) mother absent; dead prey (which was killed by deep freezing).

For evaluation, the data of two parallel experiments (two family groups with instars of the same age) were pooled. The scorpions were fed adult females of the Argentine cockroach *Blaptica dubia* (2.35±0.27 g body weight, N=66). The mean body weight in second instar *Pandinus* was 0.33±0.05 g (N=34) and 29.96±6.51 g in adult, non-gravid female *Pandinus* (N=5). Groups were separately kept in cages (40×30×20 cm) with a water dish and a hiding place. About once every ten days all three groups were simultaneously offered one *Blaptica*. The cages were checked daily. Cockroaches not eaten one day after feeding, as well as prey remains, were removed. Before and after feeding, all scorpions were weighed on a Mettler laboratory balance. Mean weight ± standard deviation are reported.

Table 1. Behavioral responses of female *Pandinus imperator* stimulated by substrate vibrations. Eight adult females without offspring and family groups (four mothers with second instars) were tested. Statistics: χ^2=97.08, df=2; P<0.0001 (m×n-contingency table).

	Female behavior (% responses)			
State of female	No response, escape, defense	Orientation movements	Attack, stinging	*n*
Non-pregnant (N=8), no offspring	70.3	28.1	1.6	64
Mother (N=4) with second instars	7.8	48.4	43.8	153

N refers to the number of individuals tested, n to the number of observations. For statistics, Mann-Whitney *U*-test, Kruskal-Wallis *H*-test and χ^2-tests were used (see Sachs 1984).

3. Results and discussion

3.1. Female behavior

Pandinus imperator is one of the largest extant scorpion species, and probably the heaviest (Krapf 1988). Normally, these scorpions do not react aggressively when touched, contrary to buthids like *Androctonus*. However, after delivering its young, the *Pandinus* female's behavior changes significantly (Table 1); the same was observed in *Heterometrus* spp. Both scorpionids, which respond very sensitively to substrate vibrations (Krapf 1986a), were stimulated by scratching the ground with a pair of pincers. Females without young tried to escape or showed defensive postures in most cases. In contrast to these non-aggressive individuals, mothers with offspring turned quickly towards the stimulus source. In 67 of all 153 cases, they vigorously grasped the forceps or even tried to sting, which is quite unusual for *Pandinus imperator*. In this situation, intruding conspecifics were sometimes seriously injured. Potential prey was always captured. Surprisingly, young were never harmed in the course of such fights, though they often were in close contact even with their mother's snapping chelae. The quick discrimination between intruder, prey, and offspring was probably mediated by the numerous chemosensitive hairs on the pedipalps. Chemoreception of prey in scorpions following contact with the chelae has been demonstrated earlier (Krapf 1986b). Females of *Euscorpius carpathicus* (L.) recognize their young through chemical scents (Vannini et al. 1978). But, as in most other scorpion species, maternal behavior in *Euscorpius* normally ends within a few weeks, shortly after the first molt of the young. In *Pandinus*, however, at least under laboratory conditions, the female tolerates young, which are now 18 months old. They are still associated with their mother. Especially for younger stages, the aggressive behavior of the female probably provides protection from predators, which are numerously reported for scorpions (Polis et al. 1981).

3.2. Family cohesion

About a week after the first molt, the second instars leave their mother's back. It was observed that even in large terraria with many hiding places the young were normally found in close contact with their mother. The aggregation tendencies of second instars and their mother were tested in an arena. In the first experiment, mother and young were free to choose one of four shelters (Table 2). This experiment was repeated twelve times consecutively. Of 144 young tested, 48.6% aggregated under the female's shelter. The observed distribution to the four shelters is significantly different from a uniform distribution (χ^2=85.72, *df*=3, *P*<0.0001). In the field, offspring probably leave their mother rarely before finally dispersing. The same is reported in the burrow-inhabiting *Scorpio maurus* (L.) (Shachak & Brand 1983) and in *Didymocentrus caboensis* (Williams) (Polis & Lourenço 1986).

Did the *Pandinus* mother act as an attractant that promoted aggregations of the young? To answer this question, the female was put in an enclosure. Table 3 shows the distribution of the second instars (*N*=12, 14 trials), which could

Table 2. Aggregation behavior of a family group of *Pandinus imperator* (mother with 12 second instars). All animals were free to choose a shelter. Shelter M is the shelter in which the mother was found. After each trial all scorpions were released into the center of the arena; data from 12 trials are pooled.
Statistics: χ^2=85.72, *df*=3; *P*<0.0001 (χ^2-test).

Shelter no:	M=1	2	3	4	n
% aggregated	48.6	38.9	10.4	2.1	144

Table 3. Aggregation behavior of 12 second instars of *Pandinus imperator*, which were free to choose one of four shelters. The mother was enclosed in shelter M. After each trial all young were released into the center of the arena. Data from 14 trials are pooled.
Statistics: χ^2=164.24, *df*=3; *P*<0.0001 (χ^2-test).

Shelter no:	M=1	2	3	4	n
% aggregated	63.7	29.2	6.0	1.2	168

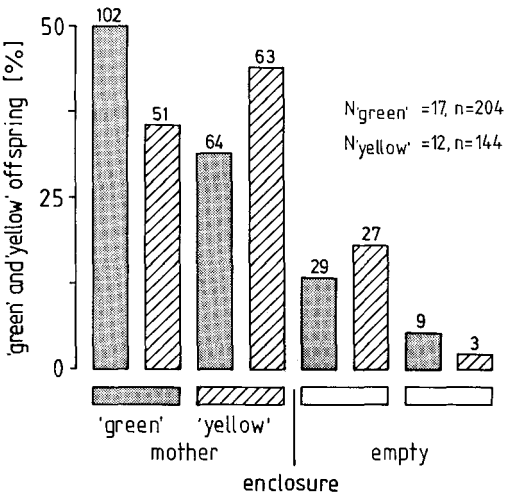

Fig. 1. The distribution of second instars of two unrelated family groups of *Pandinus imperator* ('green' and 'yellow') in an arena with four shelters. The mothers of both families were each enclosed under a shelter; two enclosures were empty. The distributions of 'green' and 'yellow' offspring are significantly different (χ^2=7.84, *df*=2, *P*=0.02; m×n contingency table).

freely move around the arena. Of all 168 young tested, 107 (=63.7%) preferred the mother's enclosure. This result differs significantly from the expected value (χ^2=164.24, *df*=3, *P*<0.0001). It suggests that the hiding place of the mother attracts young scorpions, which appear to search for her.

But is it their mother they try to find; can they discriminate between their own and an alien mother? In a choice experiment, two unrelated family groups (female and offspring) were tested. The specifically paint-marked second instars of the two families were comparable in age and size ('green': 0.333±0.034 g, *N*=17; 'yellow': 0.349±0.026 g, *N*=12; *U*-test of differences in mean weight: *z*=1.51, n.s.). The two females were enclosed under separate shelters. The 29 offspring, which never showed any sign of interfamiliar aggression, were jointly released into the arena. The young had the opportunity to choose between the two mothers' places and two empty shelters. The result (pooled data from 12 trials) is shown in Fig. 1.

The difference in the distribution of 'green' and 'yellow' instars is significant (χ^2=7.84, *df*=2, *P*=0.02; m×n-contingency table). The offspring of both families aggregated in half ('green') and nearly half ('yellow') of possible cases (*n*=204 vs *n*=144) under their own mother's shelter. A mother never harmed alien offspring. In the field, *Pandinus imperator* were found in mixed age groups, which at least partly appeared to be family groups. It is still unclear whether different family groups may occur in close vicinity under one log or in one termite mound, which are the preferred shelters of *Pandinus*. Under these circumstances, however, a family-specific recognition of the mother may be adaptive for the offspring, to avoid intraspecific predation by males or non-gravid females (Vannini et al. 1978).

3.3. Feeding experiment

In the laboratory, I often observed groups of older offspring of *Pandinus* and *Heterometrus* jointly killing prey. Second instars tried to attack large insects also, but normally they did not succeed in subduing large prey. It was assumed that the presence of the mother is advantageous to the youngs' access to food. To test this hypothesis, sibling groups of *Pandinus imperator*, with their mother present (a) or absent (b, c), were offered very large prey that were live in two treatments (a, b) and dead in the other (c). Up until this time, the offspring had never been fed. The growth of the young from the age of 86 days to 276 days in groups a, b, and c is shown in Fig. 2.

Most strikingly, all offspring in group (b) did not survive past 157 days; they never succeeded in killing a cockroach and starved to death. In general, cannibalism is very low in *Pandinus*, but in (b) four young were eaten by siblings (compared to one case of undetermined cause of mortality in group a). From the age of 94 to 157 days, the difference in the distribution of body weights in groups a, b, and c is highly significant (*H*=14.31 to 16.57, *df*=2, *P*<0.001; *H*-test). There is no difference in mean body weight of group a and c (*z*=0.07 to 0.85, *U*-test, n.s.). Though both groups were offered the same amount of food, one should keep in mind that in group (a) the mother was present, and she is about a hundred times heavier than an

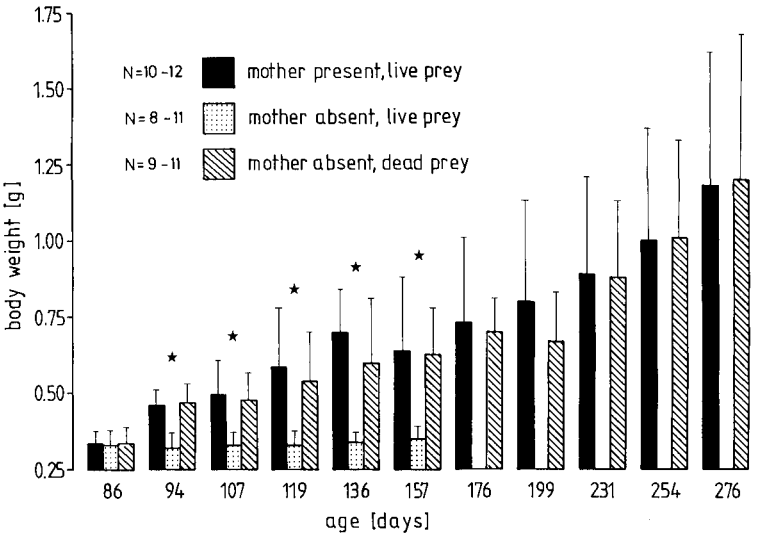

Fig. 2. Growth and age of second instar *Pandinus imperator* during a feeding experiment. The mean body weights of three groups are compared. The mother was present in one (black) and absent in two groups (dotted/striped). About once every ten days all groups were offered one large adult female cockroach (*Blaptica dubia*), which was live in two (black/dotted) and dead (striped) in one treatment. Standard deviation of the mean is indicated by line at top of bar. Statistics: H-test (* $P<0.001$).

early second instar. In fact, in the seven months of the experiment, the female ate very little. On the other hand, the cockroaches were seized and crushed exclusively by the mother. An analysis of prey remains in the field has shown that the greatest proportion of *Pandinus*' diet consists of diplopods and large beetles. These arthropods are large prey, difficult and dangerous for individual young scorpions to subdue even in a group, but easily killed by adults. As shown in group c, scorpions may feed on dead prey, too, which probably is rarely found in nature by juvenile scorpions. In the laboratory, groups of about 30 young *Heterometrus spinifer* (Peters) jointly fed on dead cockroaches and even on a dead young rat they had dragged into their shelter (Krapf 1986a). Dismembering the carcass was rendered possible only by cooperation. The behavior exhibited by *Pandinus* and *Heterometrus* resembles the group feeding in the 'family spider' *Stegodyphus mimosarum* Pavesi (Ward & Enders 1985). In this genus, cooperative brood care is highly developed (Seibt & Wickler 1988).

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