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The influence of temperature on the development time of three oribatid mite species (Acari, Oribatida)

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Abstract. Oribatid mites are one of the arthropod groups with classical development cycle. They go through six morphological stages, each separated by a moult. The development time of oribatids is generally slow. Moreover, it has been documented that temperature, soil acidity, humidity, amount and quality of food and disturbance affect the life cycle (Luxton 1975, Maraun & Scheu 2000). Furthermore, it is assumed that the generation time depends mostly on the genetic mode. All variations in development time caused by the environment (temperature or quality of food) are smaller than variations within families or order, which are based on strong genetic basis (Siepel 1994).

The aim of this paper is to study the development time of two *Ceratoppia* (Ceratoppidae) and one *Nanhermannia* (Nanhermanniidae) species. Obtained data allow comparisons between the development time of two sexual species: *Ceratoppia bipilis* (Hermann, 1804) and *C. quadridentata* (Haller, 1882) and one parthenogenetic species *Nanhermannia* cf. *coronata* Berlese, 1913 with the earlier studied *N. Nana* (Nicolet, 1855).

Recent studies indicated that in laboratory the duration of egg and nymphal stages of *C. bipilis* was shorter than in *C. quadridentata*, while durations of moults were approximately identical. The development of *Ceratoppia bipilis* from egg to adult lasted 43-65 days, whereas that of *C. quadridentata* – 57-89 days. The development of *Nanhermannia* cf. *coronata* was similar to earlier examined *N. nana* and lasted 112-149 days. At 20 ºC the life cycle of *Ceratoppia* was much shorter than that of *N.* cf. *coronata*. Our findings indicate that mites from the Brachypylina group generally develop much faster than those of early-derivative mites. However, this fact contradicts earlier suggestions, that the generation time of parthenogens is shorter than that of sexual species.

Key words: *Ceratoppia bipilis* (Hermann, 1804), *C. quadridentata* (Haller, 1882) and *Nanhermannia* cf. *coronata* Berlese, 1913, duration of development.

Introduction

Studies on the development of oribatid mites are an important aspect in acarology. The ontogeny and the duration of development for these animals have usually been unsufficiently investigated. The data, even if available in the literature, are not always suitable for comparison and interpretation. The problems are caused by the use of various cultivation techniques (Shaldybina 1969a, Seniczak 1972), lack of recorded lengths of development for separate stages (Hartenstein 1962, Block 1965) or unavoidable fluctuations of air temperature (Weigmann 1975). Moreover, it is generally known that environmental factors (tempe-

rature, soil acidity, humidity, amount and quality of food, disturbances) and the density of other microarthropods can partly affect the development duration of moss mites (Shaldybina 1969b, Siepel 1994, Maraun & Scheu 2000, Uvarov 2003). However, the largest influence on the generation time is that of the genetic mode of the order or family. Siepel (1994) noted that all variations in development time caused by the environment are smaller than variations within families or order.

The problems with developmental studies may be caused by the reproduction mode of moss mites. It is assumed that the generation time of parthenogens is shorter than that of sexual species (Ghilarov 1982, Ryabinin & Pan'kov 1987). However, data about relationship between generation time and mode of reproduction are rare (Norton & Palmer 1991).

Nevertheless, it is generally known that oribatid mites have low metabolic rates, slow development, low fecundity, low number of eggs and juvenile survival, so they exemplify the "K-selected" organisms (MacArthur & Wilson 1967, Crossley 1977). The development duration from egg to adult may vary from several months to two years in temperate forest soils (Luxton 1981) and the generation time at 18 ºC may take from 33 days in *Oppia concolor* (Nannelli 1975) to 400 days in *Steganacarus magnus* (Webb 1977). However, in warmer climates the number of generations per year may be very high (Norton & Palmer 1991). Cool climates prolong the life cycles of moss mites. It has been shown that *Tectocepheus velatus* (Michael 1880) from northern Norway lives two or more years (Solhøy 1975) and the duration of nymphal stages of the Antarctic species *Alaskozetes antarcticus* (Michael 1903) may be more than three years (Burn 1986). Recently, the development duration of *Scutovertex rugosus* Mihelcic, 1957 and *S. perforatus* Sitnikova, 1975 was investigated at two temperatures (Ermilov et al. 2008). Similarly, the authors observed considerable differences that indicated a longer life cycle at lower temperatures.

Fourteen species of *Ceratoppia* genus and 34 species of *Nanhermannia* genus have been described so far (Subías 2004). In Russia, nine species of *Ceratoppia* and eleven species of *Nanhermannia* genus have been recorded. However, only four species are widespread in the European part of Russia (the Nizhniy Novgorod region): *N. nana* (Nicolet, 1855), *N. coronata* Berlese, 1913, *Ceratoppia bipilis* (Hermann, 1804) and *C. quadridentata* (Haller, 1882). So far, the data on development duration have concerned two species only: *C. bipilis* and *N. nana* (Sengbusch 1958, Krivolutsky 1995, Ermilov 2004, Michael 1884-1888).

The aim of this paper is to examine and compare the development time of two sexual species from the family Ceratoppiidae: *Ceratoppia bipilis* (Hermann, 1804) and *C. quadridentata* (Haller, 1882) and one parthenogenetic *Nanhermannia* cf. *coronata* Berlese, 1913 (Nanhermanniidae) with the earlier studied parthenogenetic species *N. nana* (Nicolet, 1855). The cultivation of the studied species was carried out in laboratory under 100% humidity, at two temperatures and with the surplus of food.

Material and methods

The studies on the development duration of *C. bipilis* were carried out in 2002 (experiment at 20˚C) and 2006 (experiment at 17˚C), on *C.*

quadridentata – in 2004 (experiment at 20˚C) and 2006 (17˚C), and on *N*. cf. *coronata* – in 2005-2006 (experiment at 22.5˚C) and 2007 (experiment at 20˚C). The cultures were started in March and April. All juvenile and adult specimens were collected in biotopes in the Nizhniy Novgorod region (Russia) by Dr. M.P. Chistyakov and Dr. S.G. Ermilov. The species were collected from the European part of Russia, i.e. the Nizhniy Novgorod region, northwest of Nizhniy Novgorod city. *Ceratoppia* species and *Nanhermannia* cf. *coronata* were collected from soil, moss and detritus of the Kozinskiy pine forest (Balachninskiy district).

Groups of adult specimens were cultured in plastic boxes, larvae and nymphs in culture chambers. The experiment was carried out in a surplus of food, 100% humidity and at two temperatures: 17ºC and 20ºC for *Ceratoppia* species and 20ºC and 22.5ºC for *Nanhermannia*. Exicators with boxes and chambers were covered with light-proof covers and placed in thermal cases. Because of different places of sampling, mites were fed with varied food: pleurococcal algae (*Pleurococcus* sp.), parts of lichens (*Cladonia silvatica* and *Cetraria islandica*) and raw potato.

The cultivation technique and calculations follow instructions of Sitnikova 1959, Shaldybina 1969a and Ermilov 2006. Calculations of the lower temperature threshold for development, the sum of effective temperatures and theoretical duration of development of mites follow methods presented by Chistyakov 1970 and Ermilov et al. 2004.

Results

All adult specimens of *C. bipilis* ate mainly pleurococcal algae (*Pleurococcus* sp.), and only rarely parts of lichens (*Cladonia silvatica* and *Cetraria islandica*). The adult individuals of *C. quadridentata* ate *Pleurococcus* sp. and *Cladonia silvatica* in equal frequency. The adult specimens of *N*. cf. *coronata* ate *Pleurococcus* sp. and raw potato. After several days females started to deposit eggs. The hatched larvae and all nymphs ate only *Pleurococcus* sp.

Because the development of studied species was measured at two temperatures, there was an opportunity to calculate theoretical duration of development (*n*), following the equations of Chistyakov (1970) and Ermilov (2004):

$n = \frac{X}{T - C}$, where

X - the sum of effective temperatures

T – the ambient temperature during development

C – the lower temperature threshold for development.

The sum of effective temperatures was calculated as:

$X = (T - C) \cdot t$, where

t – number of days when the temperature exceeded the development threshold

The lower development threshold temperature was calculated as:

$$C = \frac{T \cdot t - T_1 \cdot t_1}{t - t_1}$$

As a result:

$$C_1 = \frac{20^\circ \cdot 43.2 - 17^\circ \cdot 64.5}{43.2 - 64.5} \approx 10.915^\circ$$

(*C. bipilis*)

$$C_2 = \frac{20^\circ \cdot 57.5 - 17^\circ \cdot 88.5}{57.5 - 88.5} \approx 11.435^\circ$$

(*C. quadridentata*)

$$C_3 = \frac{22.5^\circ \cdot 112.0 - 20^\circ \cdot 148.4}{112.0 - 148.4} \approx 12.307^\circ$$

(*N. coronata*).

The sum of effective temperatures for all three species was:

$$X_1 = (20^\circ - 10.915^\circ) \cdot 43.2 \approx 392.4^\circ$$

or

$$X_1 = (17^\circ - 10.915^\circ) \cdot 64.5 \approx 392.4^\circ$$

(*C. bipilis*)

$$X_2 = (20^\circ - 11.435^\circ) \cdot 57.5 \approx 492.4^\circ$$

or

$$X_2 = (17^\circ - 11.435^\circ) \cdot 88.5 \approx 492.4^\circ$$

(*C. quadridentata*)

$$X_3 = (22.5^\circ - 12.307^\circ) \cdot 112.0 \approx 1141.6^\circ$$

or

$$X_3 = (20^\circ - 12.307^\circ) \cdot 148.4 \approx 1141.6^\circ$$

(*N. coronata*).

Theoretical duration of development was calculated as (the results are given in Table 3):

$$n = \frac{392.4^\circ}{T - 10.915^\circ} \quad (C.\ bipilis)$$

$$n = \frac{492.4^\circ}{T - 11.435^\circ} \quad (C.\ quadridentata)$$

$$n = \frac{1141.6^\circ}{T - 12.307^\circ} \quad (N.\ coronata).$$

The present studies have shown that development of *C. bipilis* from the egg to the adult stage lasts on average 64-65 days at 17ºC and 43-44 days at 20ºC, development of *C. quadridentata* – 88-89 days at 17ºC and 57-58 days at 20ºC, and development of *N.* cf. *coronata* – 148-149 days at 20ºC and 112 days at 22.5ºC. Lower development threshold temperature for all species is above 10ºC. The sum of effective temperatures, which are required for development of *Ceratoppia* species are 2-3 times lower than for *N.* cf. *coronata*. Length of development of *Ceratoppia* species and *N.* cf. *coronata* is given in Table 1. The comparison of development terms of *N.* cf. *coronata* nymphs is given in Table 2.

Discussion

The duration of development in the examined species was different. At 20 ºC the development of *Ceratoppia* was much shorter than that of *N.* cf. *coronata*. This may be explained by the fact that mites from Brachypylina group (represented by *C. bipilis* and *C. quadridentata*) generally develop faster than those of early-derivative Macropylina (represented by *N.* cf. *coronata*) (Lebrun 1970, Norton & Palmer 1991). This finding is in contrast with earlier suggestions (Ghilarov 1982, Ryabinin & Pan'kov 1987), that the generation time of parthenogenetic species is shorter than that of sexual species.

Development within *Ceratoppia* species had dissimilarities as well. The duration of egg and nymphal stages of *C. bipilis* was shorter than in *C. quadridentata*, whereas durations of moults (periods of rest) were approximately identical. We noted that observed lengths of development in *C. bipilis* (53-73 days at 17ºC and 40-51 days at 20ºC) are comparable with those obtained by Krivolutsky (1995; 49-87 days at 18ºC, 79 days at room temperature).

Table 1. The development duration of *Ceratoppia bipilis*, *C. quadridentata* and *Nanhermannia* cf. *coronata*

Stage	*Ceratoppia bipilis* (in days)					
	17°C			20°C		
	Min	Max	Average ± SE	Min	Max	Average ± SE
Egg	3	11	5,1±0,2	2	6	2,6±0,1
Larva	7	15	10,2±0,2	3	12	5,2±0,5
Moult I	3	7	4,1±0,1	2	6	2,9±0,3
Proto-nymph	5	14	7,9±0,3	4	7	5,1±0,4
Moult II	3	7	4,5±0,2	2	5	3,5±0,5
Deuto-nymph	6	13	8,9±0,3	6	15	8,2±2,0
Moult III	4	7	5,1±0,2	3	4	3,7±0,2
Trito-nymph	9	22	14,2±0,8	5	9	7,0±2,0
Moult IV	4	9	5,8±0,4	5	5	5,0±0,0
Egg-Adult	57	73	64,5±1,4	40	51	43,2±2,0

Stage	*C. quadridentata* (in days)					
	17°C			20°C		
	Min	Max	Average ± SE	Min	Max	Average ± SE
Egg	10	19	13,0±0,3	5	13	7,3±0,3
Larva	8	16	10,5±0,3	5	9	7,0±0,2
Moult I	3	6	4,0±0,1	2	4	3,2±0,1
Proto-nymph	9	17	11,6±0,2	7	10	8,4±0,1
Moult II	4	7	4,7±0,1	2	4	3,3±0,1
Deuto-nymph	10	17	11,8±0,5	4	9	6,1±0,2
Moult III	4	8	5,1±0,2	2	6	3,7±0,2
Trito-nymph	16	31	22,4±1,1	10	20	13,7±0,6
Moult IV	5	10	6,4±0,4	4	7	5,0±0,1
Egg-Adult	75	97	88,5±2,0	52	62	57,5±0,7

Table 1. (Continued)

Stage	*Nanhermannia* cf. *coronata* (in days)					
	20°C			22.5°C		
	Min	Max	Average ± SE	Min	Max	Average ± SE
Egg	6	15	10,0±0,1	6	8	6,5±0,2
Larva	12	28	19,8±0,4	13	20	15,3±0,6
Moult I	4	9	6,0±0,1	4	8	5,7±0,3
Proto-nymph	16	32	25,4±0,8	11	31	20,6±1,3
Moult II	5	11	8,0±0,3	5	11	7,1±0,3
Deuto-nymph	20	37	26,5±0,8	12	26	19,6±0,9
Moult III	7	15	10,1±0,4	6	12	9,0±0,4
Trito-nymph	21	40	28,7±1,2	9	26	16,9±1,4
Moult IV	10	16	13,7±0,9	10	13	11,0±0,2
Egg-Adult	129	165	148,4±2,4	105	124	112,0±1,4

Table 2. The comparison of development time of *N*. cf. *coronata* nymphs at two temperatures (in days, PR: period of rest).

Stage	20°C	22.5°C
Protonymph + PR II	33.4	27.7
Deutonymph + PR III	36.6	28.6
Tritonymph + PR IV	42.4	27.9

The development time of *N*. cf. *coronata* at 22.5°C (112 days) was similar to that of *N*. *nana* (Nicolet, 1855) examined by Sengbusch (1958). His experiments were carried out at 25°C and this species developed in 111 days. The most important difference between these two parthenogens was the duration time of eggs (*N*. cf. *coronata* proceeds twice as fast as *N*. *nana*).

It is generally known, that temperature modifies the generation time of oribatid mites (Uvarov 2003, Ermilov 2004). Higher temperature affects respiration, trophic activity, reproduction and development favorably. In the present study we have shown that development of *C*. *bipilis* and *C*. *quadridentata* at 20°C is 1.5 times shorter than at 17°C, whereas development of *N*. cf. *coronata* at 22.5°C is about 1.3 times shorter than at 20°C.

Table 3. The development duration of *Ceratoppia bipilis*, *C. quadridentata* and *Nanhermannia* cf. *coronata* (* calculated theoretically).

Temperature (in °C)	Duration of development (in days)		
	C. bipilis	***C. quadridentata***	***N.* cf. *coronata***
16	77*	107*	-
17	64	88	-
18	55*	75*	-
19	48*	65*	170*
20	43	57	148
21	38*	51*	131*
22	-	-	117*
22.5	-	-	112
23	-	-	106*

Furthermore, each subsequent nymphal stage and its corresponding period of rest are longer than the previous. However, the reduction of temperature causes more considerable differences in duration between stages.

The data support previous observations (Norton & Palmer 1991) that increase in temperature speeds up the development of oribatid mites, but do not support the prediction that a parthenogenetic species would have shorter generation time than the sexual species.

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