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LIFE HISTORY AND POPULATION DYNAMICS OF THE MYCOPHAGOUS MITE TARSONEMUS GRANARIUS LINDQUIST (ACARINA : TARSONEMIDAE) *

BY N. D. G. WHITE ** and R. N. SINHA ***

ABSTRACT: Mites of Tarsonemus granarius Lindquist were reared individually at 30°C and 90 % relative humidity (RH) on the fungus Alternaria alternata (Fr.) Keissler. A life table was constructed; the intrinsic rate of increase was 0.162 offspring/day, net reproductive rate was 5.42 times and mean generation time was 10.43 days; fertilized eggs developed into females (arrhenotoky) and unfertilized eggs developed into males. Populations of T. granarius on agar slants inoculated with A. alternata were observed weekly for 8 weeks at 30°, 25°, and 20°C; 90 % and 75 % RH. The number of eggs and sex of the offspring were determined. Populations increased most rapidly at 30°C and 90 % RH. Fungi of three species of the Aspergillus glaucus group were found to be an inferior food-source for T. granarius. Population fluctuations of T. granarius under granary conditions were observed at monthly intervals for 21 months in a circular metal bin containing 45.72 tonnes of rapeseed which was stored for 5 years.

RESUME : Les Acariens de l’espèce Tarsonemus granarius Lindquist ont été individuellement élevés à 30°C et à une humidité relative de (RH) 90 %, sur un champignon Alternaria alternata (Fr.) Keissler. Une table de développement a été établie ; le taux intrinsèque d’accroissement a été de 0,162 ♀ écloses/♀/jour, le taux net de multiplication a été de 5,42 fois, et la durée moyenne d’une génération a été de 10,43 jours ; les œufs fertilisés se sont développés en femelles (arrhénotoky) et les œufs non fertilisés en mâles. Les populations de T. granarius sur des milieux ensemencés d’A. alternata ont été observés hebdomadairement pendant 8 semaines, à 30°C, 25°C et 20°C, à 90 % et 75 % de R.H. Le nombre des œufs et, à l’éclosion, le sexe ont été déterminés, Les populations se sont rapidement accru surtout à 30°C et 90 % de RH. Les champignons de trois espèces du groupe Aspergillus glaucus se sont révélés inférieurs comme aliment pour T. granarius. Les fluctuations de population de T. granarius en grenier ont été observées mensuellement pendant 21 mois dans un coffre métallique circulaire qui contenait 45,72 tonnes de graines de colza emmagasinées depuis cinq ans.

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The glossy grain mite, *Tarsonemus granarius* Lindquist, is a mycophagous mite commonly found in stored grain (Sinha, 1964a; Lindquist, 1972), grain dust, and spillage (Hughes, 1976). It has also been found in Japan on granary floors and rice straw in the field (Sinha, 1968). In storage the abundance of *T. granarius* is related to moisture content of the grain, depth of bulk-stored grain, temperature, and storage fungi such as *Chaetomium* and *Aspergillus*. *T. granarius* was the only arthropod species that showed a close relationship with a number of seed-borne fungi during an 8-year study on wheat storage in Canadian granaries (Sinha, et al., 1969). This mite (mentioned under the synonym *Tarsonemus waitei* Banks), reproduces relatively well while feeding on fungi of the species *Alternaria alternata* (Fr.) Keissler, *Chaetomium* sp., *Curvularia tetramera* (McKinney) Boldyn, *Fusarium moniliformae* Sheldon, and *Hormodendrum* (Cladosporium) *cladosporoides* (Fr.) Saccardo, and to a lesser extent on fungi of various *Aspergillus* spp. (Sinha, 1964b). A positive correlation ($P \leq 0.01$) between high population densities of *T. granarius* (up to 1500 mites per 150 ml wheat) and occurrence of *Alternaria alternata* infection on 10-45% of the wheat kernels, and a positive correlation ($P \leq 0.05$) between lower population densities of *T. granarius* (up to 175 mites per 150 ml wheat) and infection of as much as 50% of the kernels by fungi in the *Aspergillus glaucus* species group was reported by White & Sinha (1979).

Although *T. granarius* is an important cosmopolitan, bioindicator species in the stored-grain ecosystem, and has a distinctive mode of reproduction, no serious study of its life strategy has been undertaken. This research was conducted to determine the intrinsic rate of increase and type of reproduction, in the laboratory, as they relate to regulation of the acarine numbers in laboratory and granary populations.

### Materials and Methods

Stock cultures of *T. granarius* were maintained on Czapek agar slants (Czapek solution agar, Difco Laboratories, Detroit, Mich., U.S.A.) inoculated with *Alternaria alternata* in 14.5 x 1.75 cm glass tubes plugged with non-absorbent sterile cotton and maintained at room temperature ($22 \pm 2^\circ C$) and relative humidity (55 ± 5% RH).

For individual rearing to determine the rate of population increase, 1 adult female was placed in a modified Robertson cell (Solomon & Cunnington, 1964) and allowed to deposit 1 egg on *A. alternata* agar, after which the adult was removed. The mite developing from the egg was followed throughout its life. Offspring were removed once their sexes were determined. Males were placed in cells with adult females for 1 day. All cells were placed in a desiccator above a KOH solution that maintained a constant RH of 90% (Solomon, 1951) at 30 ± 1°C, and observed daily for rate of development and oviposition data.

To determine the effects of temperature and RH on the rate of increase of *T. granarius* a series of 24 agar slants identical to those used for the stock cultures were inoculated with *A. alternata* and 4 fungus-free agar slants served as controls. Five adult female *T. granarius* taken from populations containing males and females were placed in each tube 3 days after initial inoculation of the agar. Groups of 4 tubes were placed in each of 6 desiccators containing KOH/H₂O solutions to maintain the following conditions ($\pm 1^\circ C, \pm 2 \% RH$): 20°C, 75% RH; 20°C, 90% RH; 25°C, 75% RH; 25°C, 90% RH; 30°C, 75% RH; 30°C, 90% RH. Mites on the fungus-free agar were placed in a chamber at 25°C, 75% RH. Females, males and eggs were counted at weekly intervals for 8 weeks under a binocular microscope. Analyses of variance were used to determine if differences in numbers occurred between the 2 RHs. Reproductive rates of *T. granarius* populations
feeding on fungi of 3 species of the *Aspergillus* glaucus group — *A. repens* de Barry, *A. amstelodami* (Mang.) Thom and Church, and *A. ruber* (Konig, Spiekermann, and Bremmer) Thom and Church — were determined by placing groups of 5 females on agar slants similar to those previously described. Four replicates were used for each fungus. The tubes were held at 30°C and 90% RH and the population size and sex ratio were observed after 2 weeks.

Population fluctuations of *T. granarius* under granary conditions were studied in 45.72 tonnes of rapeseed (*Brassica napus* cv. Zephyr) harvested in 1973 and stored in a circular, galvanized steel bin (556.3 cm diam.) at Glenlea, Manitoba. Samples (300 ml) were taken monthly for 5 years from a fixed location (where *T. granarius* infestation was continuous from 1977-1979) about 150 cm from the wall at a depth of 70 cm from the surface of the bulk seed using a brass torpedo probe. Grain temperature (±1°C) was measured with copper-constantan thermocouples and a potentiometer (Minneapolis-Honeywell Regulator Co., Philadelphia, U.S.A.; model No. 2736). Moisture content of the seed was determined on a wet weight basis, by a dielectric moisture meter (Labtronics, Winnipeg, Canada, Model No. 919). Mites were extracted from the samples using Berlese funnels (Sinha, 1961). Seed germination and microfloral infection were determined by the filter paper method of Wallace & Sinha (1962).

**RESULTS**

**Laboratory study**

A life table was constructed for *T. granarius* mites reared individually on *A. alternata* at 30°C, 90% RH (Table I) using the methodology of Birch (1948) as modified by Laing (1968). *A. alternata* is one of the most favorable diets for *T. granarius* development and was used to maximize the reproductive potential of the mite. The intrinsic rate of increase (rm) was calculated from the life table using the formula:

\[ e^{rm} = \Sigma_{x} \frac{1}{x} \times m_{x} \]

where \( e \) is the base of natural logarithms, \( x \) is the age of individuals in days, \( 1_{x} \) is the number of individuals alive at age \( x \) as a proportion of 1, and \( m_{x} \) is the number of female offspring produced per female in the age interval \( x \). The net reproductive rate \( (R_{0}) \), mean generation time \( (T) \), and finite rate of increase \( (\lambda) \) were calculated with the formulas:

\[ R_{0} = \Sigma \frac{1_{x} \times m_{x}}{r_{m}} \]
\[ T = \log_{e} R_{0} \]
\[ \lambda = \text{antilog}_{e} rm \]

From the life table \( R_{0} \) was calculated to be 5.42, \( T \) was 10.43 days, \( r_{m} \) was 0.162 offspring/day, and \( \lambda \) was 1.18 times per day.

Developmental rates, longevity, and egg production were determined by observing from 14-20 rearing cells. Egg hatch occurred 1.98 ± 0.11 days after oviposition (mean ± standard error); the period from egg hatch to adult was 5.00 ±
0.63 days; and the period from egg deposition to subsequent oviposition by females was 7.06 ± 0.15 days. The longevity of females from egg deposition to death was 16.80 ± 0.92 days and the total number of eggs produced by each female was 5.40 ± 0.63. Whenever female/male individuals were reared with 1 : 1 ratio in cages, eggs produced females (arrhenotoky); virgin females laying unfertilized eggs produced males. Individually caged virgin females produced 1.83 ± 0.13 male offspring which subsequently fertilized the mother; further progeny were females.

The population structure of *T. granarius* on the agar slants containing *A. alternata* is shown in Fig. 1. The mites did not survive more than 1 week and did not reproduce on the agar controls. Significant differences were found between RH at each temperature (P ≤ 0.01) during 8 weeks. Population increase was most rapid at 30°C, 90 % RH; the increase was more gradual at 75 % RH. Mean population numbers increased to 732 and 705 respectively at week 4 (Fig. 1A, B). Populations declined rapidly as fungal food was depleted and became contaminated with excreta on the agar. Populations rose more gradually at 25°C (Fig. 1C, D) with highest numbers attained at week 7 with 1,216 mites per tube at 90 % RH and 1,099 mites per tube at 75 % RH. After reaching their maxima, populations fell rapidly as the agar dried and the food quality declined.

Populations of *T. granarius* at 20°C multiplied slowly, notably at 75 % RH, but all were increasing at week 8 as fungal mycelia on the agar was not entirely depleted (Fig. 1E, F). Even after 8 weeks only 482 and 426 mites per tube were evident at 90 and 75 % RH, respectively. The cooler temperatures appeared to slow the rate of development of the mite.

Although males were almost always present in the laboratory populations the sex ratio under different conditions of temperature and RH varied considerably (Table II). Males were always considerably lower in number than the females. The number of females increased with no corresponding rise in male numbers.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>RH %</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
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<tbody>
<tr>
<td>20</td>
<td>90</td>
<td>13.0</td>
<td>9.3</td>
<td>5.5</td>
<td>4.4</td>
<td>6.5</td>
<td>7.5</td>
<td>8.9</td>
<td>15.3</td>
</tr>
<tr>
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<td>90</td>
<td>22.0</td>
<td>6.9</td>
<td>7.1</td>
<td>11.5</td>
<td>25.1</td>
<td>49.0</td>
<td>74.9</td>
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</tr>
<tr>
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<td>90</td>
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<td>8.9</td>
<td>11.1</td>
<td>37.1</td>
<td>47.0</td>
<td>58.1</td>
<td>56.6</td>
</tr>
</tbody>
</table>

The mean number and standard error of *T. granarius* mites feeding on fungi of *Aspergillus* spp. after 2 weeks were as follows: *A. repens* — 19.3 ± 1.9 females, 2.3 ± 0.5 males; *A. amstelodami* — 58.6 ± 7.2 females, 10.8 ± 1.5 males and 2.8 ± 0.3 eggs; *A. ruber* — 32.0 ± 5.5 females, 4.0 ± 0.9 males and 11.3 ± 4.5 eggs. The number of mites observed, after 2 weeks, which fed on fungi of *Alternaria alternata* under identical environmental conditions was 306 ± 44.6 females, 52 ± 4.6 males, and 130 ± 27.5 eggs. An equilibrium in sex ratio was not evident as populations increased.

**Granary study**

To determine the pattern of population growth under natural conditions, a farm granary containing bulk rapeseed was observed. *T. granarius* was not found in samples until the fourth year of storage (1977); populations reached peak numbers between September and October in 1977, August and September, and November and December in 1978, and February and March in 1979 (Fig. 2). Temperatures fluctuated in a cyclical manner with high points near August and low points near February. Seed moisture content fluctuated between 8.9 and 11 %. *Alternaria* was not present on the seed but *Aspergillus glaucus* group species were abundant and predominant, contaminating more than 90 % of the seed after September 1977.
Fig. 1: Population dynamics of *Tarsonemus granarius* feeding on *Alternaria alternata* at 3 temperatures and 2 relative humidities.
Fig. 2: *Tarsonemus granarius* population fluctuations (only females found) and temperature in stored rapeseed monitored for 21 months; number of mites are from 300 ml samples taken from the same location.

**DISCUSSION**

Although *A. alternata* has been shown to be a favourable diet for *T. granarius*, the $r_m$ value of 0.162 is relatively low as compared to the grain mite, *Acarus siro* L., which reproduces more than twice as fast (Solomon, 1962). The net reproductive rate of 5.42, however, agrees with the rate of increase of populations in the tubes. Oviposition rate may have been slightly depressed by limitations in rearing technique, notably the difficulty in maintaining growing fungal mycelia within the rearing cells.

Adult sexual dimorphism is known in the Tarsonemidae, males being smaller and slower-moving than females, and possessing large pincer-shaped hind legs used as accessory copulatory appendages (Hughes, 1976). This condition facilitated determination of sex in this study.

Parthenogenesis is common in the Tarsonem-
midae, possibly with only females produced (Garmán, 1917), but arrenotoky or the development of unfertilized eggs into males is more common as observed in several Tarsonemus species (Beer, 1954; Krantz & Lindquist, 1979) and in T. granarius populations.

The optimal conditions for development and multiplication of T. granarius, while the environment was non-limiting, were 30°C, 90% RH with slower population growth at 25°C and 20°C (Fig. 1). The RH of 90% was more favorable than that of 75% for the multiplications of this mite. In all cases final population sizes were largely limited by deterioration of the substrate and food source. The number of mite eggs counted was lower than the number of mobile forms. One explanation for this could be that the eggs were usually laid below the mat of fungal mycelia and all eggs could not be observed. Furthermore, overlap among succeeding generations with an increase in the number of older females could be partially responsible for low egg counts. T. granarius fed and multiplied on fungi of all 3 species of the Aspergillus glaucus group tested, most notably on A. amstelodami, but all of these species were inferior food sources to Alternaria alternata. The optimal environmental conditions for Tarsonemidae generally include low light intensity, high humidity, and warm temperatures; and they can survive in the adult stage through prolonged exposure to freezing temperatures but rarely survive above 35°C (Beer, 1954). However, T. granarius can breed at temperatures of 4-10°C (Sinha, 1964a).

In the binned rapeseed T. granarius was most abundant when temperatures were above 10°C with peak populations in October 1977, September and December 1978. Population peaks in February and April 1978 and March 1979 probably consisted of overwintering adults and were presumably residual populations from previous periods. Only females were observed in samples from the rapeseed, probably indicating selective mortality of males by the extraction method. Laboratory data implies that males were present in the populations although they were not detected. The seed in the location monitored was continuously moist with an equilibrium relative humidity of 70-80% at 20°C and the only common fungi present to be consumed by T. granarius were those of the Aspergillus glaucus group. The type of fungi present determines the rate of T. granarius increase and the relatively low levels of abundance of this mite in the rapeseed studied, under otherwise favorable conditions, confirm that Aspergillus spp. are an acceptable food source but inferior to that of Alternaria which is abundant in early parts of storage of cereals and oilseeds. Population fluctuations were erratic although the numbers of T. granarius generally increased between 1977 and 1979. The population fluctuations do not seem to correspond to seasonality, which is dominated by temperature in temperate climates, although this effect may be partially explained by sampling variation. The peak levels of T. granarius numbers in 1979 are similar in size to those of a previous study where the equilibrium level of this mite occurred on wheat which was infected with A. glaucus group and stored at 30°C (White & Sinha, 1979).

The laboratory data collected in this study give some insight into the effects of temperature, humidity and food on the reproductive ability of T. granarius. The data reveal the life strategy of this mite although natural conditions seem to be far more complex and extreme. Further research on the performance of T. granarius at low temperatures and feeding on less favourable species of microflora is needed for better understanding of the factors regulating the populations of this important storage mite.

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