

## Life history and population growth parameters of *Tyrophagus putrescentiae* (Acari: Acaridae) on *Fusarium graminearum* in laboratory conditions

F. Bahrami, K. Kamali and Y. Fathipour

Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-336, Tehran, Iran.

### Abstract

The life history of an acarid mite, *Tyrophagus putrescentiae* (Schrank), on *Fusarium graminearum* Clade was investigated at  $25 \pm 1^\circ\text{C}$ ,  $60 \pm 5\%$  RH and a photoperiod of 16: 8 (L: D) h. Incubation period for egg hatch, larval and nymphal periods and adult longevity were  $2.22 \pm 0.06$ ,  $3.46 \pm 0.12$ ,  $4.84 \pm 0.16$  and  $10.05 \pm 0.9$  days, respectively. The average life span of males and females were  $22.22 \pm 1.21$  and  $19.08 \pm 1.37$  days respectively. Pre-oviposition, oviposition and post-oviposition periods were 2.22, 5.77 and 1.4 days respectively. Gross and net fecundity rates were obtained 76.2 and 23 eggs per female per generation respectively. Net reproduction rate was 12.5 female eggs per female per generation, and average daily oviposition rate was 5.7 eggs. The intrinsic and finite rates of population increase were 0.15 and  $1.16 \text{ day}^{-1}$  respectively. The mean generation time (T) and the mean doubling time (DT) were 16.74 and 4.59 days respectively. The population mainly (78%) consisted of eggs and larvae, and nymphs and adults represented only 22% of the population.

**Key words:** *Tyrophagus putrescentiae*, *Fusarium graminearum*, development, population growth parameters

### چکیده

پارامترهای زیستی کنه‌ی *Tyrophagus putrescentiae* (Schrank) روی قارچ *Fusarium graminearum* Clade در شرایط آزمایشگاهی با دمای  $25 \pm 1$  درجه‌ی سانتی‌گراد، رطوبت نسبی  $60 \pm 5$  درصد و دوره‌ی نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی مورد مطالعه قرار گرفت. طول دوره‌ی جنینی، لاروی، پورگی و طول عمر بالغین به ترتیب  $2.22 \pm 0.06$ ،  $3.46 \pm 0.12$ ،  $4.84 \pm 0.16$  و  $10.05 \pm 0.9$  روز بدست آمد. طول دوران زندگی نرها و ماده‌ها به ترتیب  $22.22 \pm 1.21$  و  $19.08 \pm 1.37$  روز محاسبه شد. طول دوران قبل از تخم‌ریزی، تخم‌ریزی و بعد از تخم‌ریزی به ترتیب  $2.22$ ،  $5.77$  و  $1.4$  روز بدست آمد. نرخ ناخالص و خالص باروری به ترتیب  $76.2$  و  $23$  تخم به ازای هر ماده در هر نسل بود. نرخ خالص تولید مثل  $12.5$  تخم ماده به ازای هر ماده در هر نسل و متوسط میزان تخم‌ریزی روزانه  $5.7$  تخم به ازای هر ماده تعیین شد. نرخ ذاتی و نهایی افزایش جمعیت به ترتیب  $0.15$  و  $1.16 \text{ روز}^{-1}$  محاسبه گردید. متوسط مدت زمان یک نسل (T) و مدت زمان دو برابر شدن جمعیت (DT) به ترتیب  $16.74$  و  $4.59$  روز بدست آمد.  $78\%$  جمعیت را تخم‌ها و لاروها و  $22\%$  آن را پوره‌ها و افراد بالغ تشکیل می‌دادند.

واژگان کلیدی: *Tyrophagus putrescentiae*، *Fusarium graminearum*، نمو، پارامترهای رشد جمعیت

### Introduction

The mould mite, *Tyrophagus putrescentiae* (Schrank), is an astigmatid mite that belongs to the superfamily Acaroidea. This species has a worldwide distribution and inhabits different environments including stored products (Czajkowska *et al.*, 1988), cultivated mushrooms (Fleurat-Lessard & Nail, 1976; Okabe *et al.*, 2001), house dusts (Berardino *et al.*, 1987; Hurtado & Parini, 1987) greenhouses, soil, mosses, litter and nests of different animals. It is saprophagous or mycetophagous and known to feed on decaying organic material in the soil

and to damage stored products (Czajkowska *et al.*, 1988). Deterioration of the quality and germinating power of the grain, and its hygienic condition are considered to be the most serious effect of mite infestation (Ardeshir, 2002). In addition, this mite can also produce allergens which induce bronchial asthma, perennial rhinitis and dermal allergies to man (Cuthbert *et al.*, 1979; Korsgaard *et al.*, 1985; Van Hage-Hamsten *et al.*, 1987; Dyne *et al.*, 1996; Solarz & Solarz, 1996; Chew *et al.*, 1999; Kronqvist *et al.*, 2000; Mekan *et al.*, 2000; Ardeshir, 2002).

*T. putrescentiae* is also a common mushroom pest mite and an important vector of dispersing weed fungi throughout mushroom cultivation facilities (Okabe *et al.*, 2001; Czajkowska, 2002). This species also feeds on different fungi including moulds (*Eutorium* and *Penicillium*), *Fusarium*, *Alternaria*, *Geotrichum*, *Mucor* and *Trichophyton* (Sinha, 1964; Coleman & McGinnis, 1970; Czajkowska, 1970; Rack, 1984; Smarz & Catska, 1987; Duek *et al.*, 2001; Hubert *et al.*, 2004). *T. putrescentiae* is an unpleasant pest damaging fungal cultures, but in the future, the use of this species in biological control may be considered (Duek *et al.*, 2001). This mite has also been recorded in house dusts and based on the investigation carried out in Caracas and Venezuela, *T. putrescentiae* was occasionally a large contributor to the bedding dust fauna. It is recommended that sensitivity to this mite should be routinely investigated in house-dust-sensitive patients (Hurtado & Parini, 1987).

The mould mite is also a major pest of ornamentals in greenhouses and has been found in flower heads of Gerbera, Narine and the apex of Kalanchoe shoots. All developmental stages of this mite were found to feed on the leaf tissue causing pin-hole damage (Czajkowska *et al.*, 1988). This species has also been seen on pollens. Chmielewski (1995) showed that bee-collected pollen was an attractive food for *T. putrescentiae*.

Gazeta *et al.* (2000) proved an association between *T. putrescentiae* and pathogenic bacteria and other microorganisms, such as *Klebsiella* sp., *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Candida albicans*. In their studies, when agar mediums were infested artificially with these mites, 100% of the plates developed bacterial colonies. The bacterial association of *T. putrescentiae* was also confirmed by Smarz (2003). Furthermore, this mite avidly consumes some nematodes including *Aphelenchus avenae* Bastin and *Meloidogyne javanica* (Treub) as a food resource (Walter *et al.*, 1986; Walia & Mathur, 1995). Regardless of its importance, however, there exists little information concerning the development and population growth parameters of *T. putrescentiae*. In the current study, more

information on bionomics of this mite species fed on *Fusarium graminearum* Clade and its acceptance as nourishment are provided.

### Materials and methods

The experiments were conducted in the laboratory at  $25 \pm 1^\circ\text{C}$  and  $60 \pm 5\%$  RH and a photoperiod of 16L: 8D h. *T. putrescentiae* was recovered from *F. graminearum* cultures in summer 2004 in Tehran, Iran. A mite-rearing cage was designated for the present study in order to rear mites individually. Glass plates having four holes with 10 mm in diameter were used as rearing cages. Paper tape was used to cover the holes. *F. graminearum* was cultured on a water-agar medium in rearing cages. Females from stock culture were introduced into a new Petri dish of *F. graminearum* and allowed to lay eggs for 24 h. Then 50 newly deposited eggs were removed and isolated in separate cells and the developmental stages were recorded every 24 h. The survival was determined for each developmental stage as well. After adults emergence they were paired (each pair (1♀ + 1♂)) was placed into a separate rearing cage) for mating. Longevity of adult males and females was recorded and the number of deposited eggs counted every day. The newly laid eggs were removed every day from rearing cages for better counting. Fresh food was added if necessary. In this study the sex ratio of imagines was also recorded. The method of Carey (1993) was used to estimate population growth parameters.

### Results

#### Immature survival and developmental times

Average immature development was  $10.52 \pm 0.34$  days at  $25 \pm 1^\circ\text{C}$  (table 1). Embryonic development was  $2.22 \pm 0.06$  days. The larval stage lasted  $3.46 \pm 0.12$  days, whereas the nymphal stage lasted  $4.84 \pm 0.16$  days. Only 38% of the eggs laid reached adult stage. Survival rate in the egg stage was higher than that of larval and nymphal stages. Variability in larval and nymphal duration was low (fig. 1).

**Table 1.** Mean developmental times and survival rates of different stages of *T. putrescentiae* reared on *F. graminearum*.

Developmental stages	Number	Development time (days)		Survival rate (%)
		Mean	SE	
Egg	46	2.22	± 0.06	92
Larva	28	3.46	± 0.12	60.87
Nymph	19	4.84	± 0.16	67.86
Egg to adult	-	10.52	± 0.34	38

### Adult life parameters

The average life span of males and females reared on *F. graminearum* was  $22.22 \pm 1.21$  ( $\pm$  SE) and  $19.08 \pm 1.37$  days, respectively (10♀, 9♂). In other words, there was a significant difference between male and female life spans ( $p \leq 0.05$ ). The average pre-oviposition, oviposition and post-oviposition periods were  $2.55 \pm 0.34$ ,  $5.78 \pm 0.85$  and  $1.4 \pm 0.18$  days, respectively. The average hatch rate was 92%. Female oviposited 2.18 eggs per day and the net fecundity and fertility rate were 23 and 21.16 respectively. Biological parameters of adults in the laboratory are given in table 2. Survival rates of male and female adults were very high; the longest lived individual died at day 29 and 27 for males and females, respectively. Egg production was high from adult aged 3-8 day-old ( $\geq 10$  egg/female/d) and decreased steadily from day 9-12 (fig. 2).

### Population parameters

Table 3 gives the population parameters and the stable age distribution. The intrinsic rate of increase and the net reproductive rate were 0.15 and 12.5 respectively, indicating a daily increase of 15% and a 12.5-fold increase from generation to generation. The population size was estimated to be doubled in 4.6 days, while the mean generation time was 16.74 days. Eggs and larvae represented 78% of the population. Nymphs and adults consisted of only 22% of the population.

### Discussion

This study provides population parameters and demographic data of *T. putrescentiae* reared on *F. graminearum* (an important host for this mite in plant pathology laboratories) at the above-mentioned laboratory conditions. Biological data can be readily used in population development models and also for developing control strategies (Papadopoulos *et al.*, 2002).

The most important reason for carrying out this research was the contamination of fungal cultures with *T. putrescentiae* in the plant pathology laboratory, Faculty of Agriculture, Tarbiat Modares University, Tehran, at the same laboratory conditions. Although this mite can feed on different fungi, several laboratory attempts to rear it on *Alternaria* were failed. Rapid growth of this fungus impeded the movement of the mite or buried its larvae and nymphs under the fungal material. Furthermore, the colony of this fungus is very dark and it is almost impossible to study the biology of this translucent mite in such a dark colony. Unlike the *Alternaria*, other fungi like *Pythium* with a very slow growth rate could not

provide enough food for the growth, development and reproduction of the mite. Therefore, the mite was reared on an almost colourless fungus, *F. graminearum*, with an average growth rate.

**Table 2.** Reproduction parameters of adult *T. putrescentiae* reared on *F. graminearum*.

Parameters	Formula	Value	Unit
Gross fecundity rate	$\sum_{x=\alpha}^{\beta} M_x$	76.2	Eggs/♀/Gen
Net fecundity rate	$\sum_{x=\alpha}^{\beta} L_x M_x$	23	Eggs/♀/Gen
Gross fertility rate	$\sum_{x=\alpha}^{\beta} M_x h_x$	0.92	Eggs/♀/Gen
Net fertility rate	$\sum_{x=\alpha}^{\beta} L_x M_x h_x$	21.16	Eggs/♀/Gen
Daily egg production	$\sum_{x=\alpha}^{\beta} M_x / e_0$	5.7	Egg/♀/Day
Daily production of fertile eggs	$\sum_{x=\alpha}^{\beta} M_x h_x / e_0$	2.01	Fertile eggs/♀/Day

$x$  = age interval in days;  $\alpha$  = age at start of reproduction;  $\beta$  = age at end of reproduction;  $L_x$  = proportion of individuals surviving to age  $x$ ;  $M_x$  = total number of eggs laid by the average females at age  $x$ ;  $h_x$  = proportion of eggs hatch for those eggs laid at age  $x$ ;  $e_0$  = number of days that females were alive.

Chmielewski (1995) studied the different life history parameters of *T. putrescentiae* on pollen at  $20 \pm 2$  °C and nearly 85% RH, which the results are almost similar to those obtained in the current study. Probably, the temperature in Chmielewski's (1995) study was 5 degrees lower than the preferred temperature for *T. putrescentiae* but the relative humidity was very appropriate.

Czajkowska (2002) investigated the average development time and life span of *T. putrescentiae* on *Fusarium oxysporum* f. sp. *tulipae* and *F. oxysporum* f. sp. *lilii* at 25°C and 85/89% RH. The average development time of *T. putrescentiae* on *F. oxysporum* f. sp. *tulipae* and *F. oxysporum* f. sp. *lilii* were 19.5 (10-25) and 17.5 (11-21) respectively, which are higher

than that of obtained in our study (10.52). The net reproductive rate ( $R_0$ ) in Czajkowska's (2002) study (119.446 on *F. oxysporum* f. sp. *tulipae* and 60.904 on *F. oxysporum* f. sp. *lilii*) are much higher than that of calculated in the current study (12.5). These differences can mainly be attributed to different strains of fungi (Czajkowska, 2002; Hubert *et al.*, 2004), to different experimental conditions (Kasuga & Amano, 2000; Thind & Dunn, 2002) and probably to different mite strains (Chmielewski, 1995; Czajkowska, 2002).

**Table 3.** Population parameters of *T. putrescentiae* reared on *F. gramineum*.

Parameters	Formula	Value	Unit
Net reproductive rate ( $R_0$ )	$\sum_{x=\alpha}^{\beta} l_x m_x$	12.5	♀/♀/Gen
Intrinsic rate of increase ( $r$ )	$\sum e^{-rx} l_x m_x = 1$	0.15	1/Day
Finite rate of increase ( $\lambda$ )	$e^r$	1.16	Per day
Intrinsic rate of birth ( $b$ )	$1 / \sum_{x=0}^{\omega} l_x e^{-rx}$	0.24	1/Day
Intrinsic rate of death ( $d$ )	$b - r$	0.09	1/Day
Doubling time (DT)	$\frac{\ln 2}{r}$	4.6	Days
Mean generation time (T)	$\sum_{x=\alpha}^{\beta} x l_x m_x / \sum_{x=\alpha}^{\beta} l_x m_x$	16.7	Days
Age distribution	$e^{-rx} l_x / \sum_{x=\alpha}^{\omega} e^{-rx} l_x$		(%)
Eggs		53	
Larvae		25	
Nymphs		11	
Adults		11	

$\alpha$  = age at start of reproduction;  $\beta$  = age at end of reproduction;  $\omega$  = maximum age;  $l_x$  = survival rate between the ages  $x$  and  $x + 1$ ;  $m_x$  = number of female progeny produced by an average female at age  $x$ .

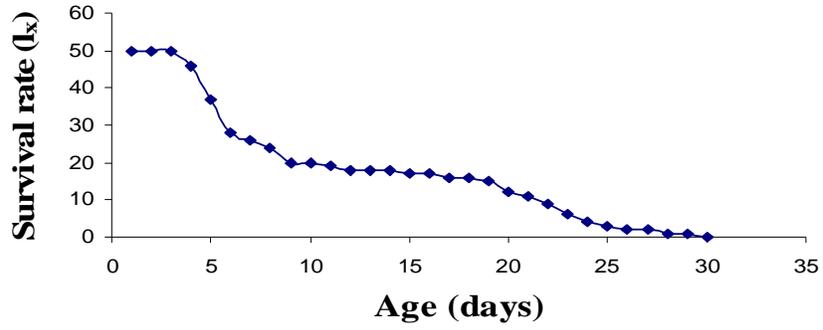


Figure 1. The survival rate of *T. putrescentiae*

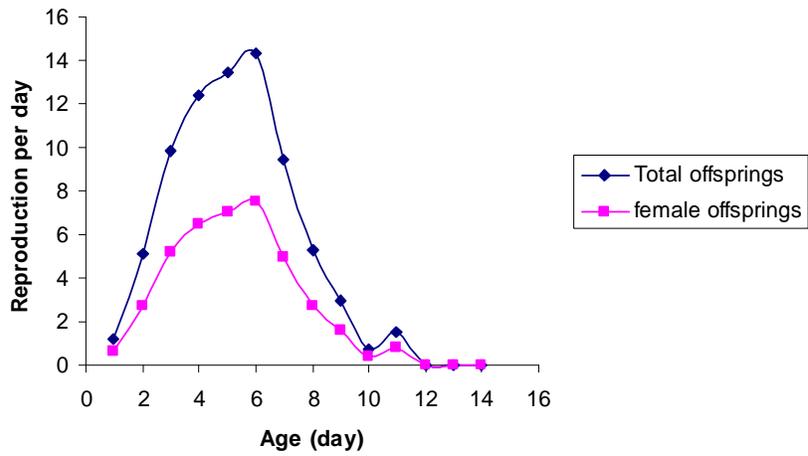


Figure 2. Daily reproduction rate in *T. putrescentiae*.

In our study, the longevity of adult males exceeded that of adult females. This is in accordance with Chmielewski (1995) and Czajkowska (2002). Baumhover (1965) and Guerra *et al.* (1972) found that reproductive cost - which is higher in females than in males - hormonal differences as well as other behavioural and physiological differences between the two sexes, may be responsible for the differences in life expectancy between the two sexes. In other words, the longevity of females is influenced by the number of eggs laid and the longevity of males depends upon the frequency of mating. According to Boczek & Czajkowska (1974), virgin females of *T. putrescentiae* reared in 95-100% RH and kept without any food lived only for a slightly shorter period than the reproducing females on an optimal diet.

Kasuga & Amano (2000) studied the life history parameters of *Tyrophagus similis* Volgin at 10, 15, 20 and 25°C under a 14L: 10D photoperiod. In their investigation the total duration of the immature developmental stages was shorter at 25°C than at other temperatures and the lifetime fecundity was greatest at 10°C. In their experiment, *T. similis* had the highest growth potential at 25°C. Although the lifetime fecundity was the lowest at this temperature, Kasuga & Amano (2000) also investigated the survivorship of *T. similis* at 25, 30, 35, 40 and 45°C under a 14L: 10D photoperiod. *T. similis* females showed a limited survival at 35°C and higher temperatures. In addition, their survival at 53, 66, 76, 87 and 100% RH was investigated at 20°C and a photoperiod of 14L: 10D h. The females showed a limited survival at 53 and 66% RH, and this shows that both *T. putrescentiae* and *T. similis* are susceptible to low humidity but *T. similis* is better adapted to lower temperatures than *T. putrescentiae*.

Sanchez Ramos & Castanera (2001) examined the developmental rate and survival of immature stages of mould mite, *T. putrescentiae*, at seven constant temperatures, ranging from 10 to 34°C, and a relative humidity of 90 ± 5%. The larval stage was particularly susceptible to low and high temperatures with 93.6 and 54% mortality at 10 and 34°C, respectively. The optimal temperature for development and survival appeared to be 30°C. In the current study, which the experiment was carried out in a relatively low RH, the larval stage showed the most mortality (39.13%). This is in agreement with Sanchez Ramos & Castanera's (2001) results. Also, Hubert *et al.* (2004) investigated the relationship between palatability and suitability of fungi for sustaining mite population growth in the laboratory, as well as the effect of mite fungal preference on spore dispersion. Eight species of microscopic fungi, *Alternaria alternata*, *Aspergillus niger*, *A. versicolor*, *Cladosporium cladosporioides*, *Eurotium amstelodami* var. *amstelodami*, *E. amstelodami* var. *motevidensis*, *Mycocladus*

*corymbifer* and *Penicillium aurantiogriseum*, differed in their attractiveness as food and in their suitability to sustain population growth of *T. putrescentiae*. In this experiment, the results of preference for a particular fungus species and its suitability for population growth of *T. putrescentiae* were as follows: (i) preferred food and suitable for mite growth (e.g. *A. alternate* and *C. cladosporioides*); (ii) preferred, but unsuitable (e.g. *E. amstelodami* var. *amstelodami*); (iii) avoided, but suitable (e.g. *A. versicolor*, *M. corymbifer* and *E. amstelodami* var. *montevidensis*); and (iv) avoided and unsuitable (e.g. *A. niger*). With respect to fungal spore dispersion, mites had the least effect on avoided and unsuitable fungal species while preferred fungi were most influenced by mite grazing (Hubert *et al.*, 2004). This, also, was seen during our study and *T. putrescentiae* dispersed the spore of some fungi like *Alternaria* spp. and *Fusarium* spp. into the medium of other fungi in the laboratory.

The sex ratio in our study was near 1:1 and this is in accordance with Chmielewski's (1995, 2000) results, but the sex ratio of *T. putrescentiae* on *F. oxysporum* f. sp. *tulipae* and *F. oxysporum* f. sp. *lilii* was 52.9% and 62.5% respectively (Czajkowska, 2002).

Finally, with respect to this matter that the humidity condition in our study was not appropriate for *T. putrescentiae* and also considering the obtained data and its comparison with the data of previous studies like Chmielewski (1995) and Kasuga & Amano (2000) that have been conducted in similar conditions, it seems that *F. graminearum* is probably a good food source for growth, development and reproduction of *T. putrescentiae*.

## References

- Ardehsir, F.** (2002) Etude des acariens des grains de froment stockés au nord de l' Iran. Thèse du grade de Docteur (Ph.D.) Université de Gent, 154 pp.
- Baumhover, A. H.** (1965) Sexual aggressiveness of male screw worm flies measured by effect on female mortality. *Journal of Economic Entomology* 58, 544-548.
- Berardino, L., Angrisano, A., Gorli, L. & Cattaneo, M.** (1987) Allergy to house dust and storage mites in children: epidemiologic observations. *Annals of Allergy* 59, 104-106.
- Boczek, J. & Czajkowska, B.** (1974) Studies on aging in *Tyrophagus putrescentiae* (Schr.) (Acarina: Acaridae). *Proceedings of the International Congress of Acarology*, 239-243.
- Carey, J. R.** (1993) *Applied demography for biologists with special emphasis on insects*. 206 pp. Oxford University Press.
- Chew, F. T., Lim, S. H. & Lee, B. W.** (1999) Sensitization to local dust-mite fauna in Singapore. *Allergy Copenhagen* 54, 1150-1159.

- Chmielewski, W.** (1995) Pollen loads as a food of stored product mites. *Pszczelnicze Zeszyty Naukowe* 39, 169-175.
- Chmielewski, W.** (2000) The contamination of pollen loads harvested by means of pollen traps with pests. *Pszczelnicze Zeszyty Naukowe* 44, 123-131.
- Coleman, D. C. & McGinnis, J. T.** (1970) Quantification of fungus-small arthropod food chains in the soil. *Oikos* 21, 134-137.
- Cuthbert, O. D., Brostoff, J., Wraith, D. G. & Brighton, W. D.** (1979) "Barn allergy": asthma and rhinitis due to storage mites. *Clinical Allergy* 9, 229.
- Czajkowska, B.** (1970) Development of *Tyrophagus* species on various fungal food substrates. *Zeszyty Problem Nauki Rolniczej* 109, 217-227.
- Czajkowska, B.** (2002) Development of acarid mites on *Fusarium oxysporum* - a pathogen of stored bulbs/corms of ornamental plants. *Bulletin of the Polish Academy of Sciences* 50, 37-48.
- Czajkowska, B., Van de Vrie, M. & Kropczynska, D.** (1988) Mites of the genus *Tyrophagus* as pests of ornamentals in greenhouses. *Mededelingen van de Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent* 53, 799-809.
- Duek, L., Kaufman, G., Palevsky, E. & Berdicevski, I.** (2001) Mites in fungal cultures. *Mycoses* 44, 390-394.
- Dyne, D., Campion, K. & Griffin, P.** (1996) Occupational allergy among workers producing arthropods for organic pest control purposes. *Annals of Agricultural and Environmental Medicine* 3, 33-36.
- Fleurat-Lessard, F. & Nail, P.** (1976) Les acariens du champignon de couche. *Pépiniéristes Horticulteurs Maraichers* 167, 29-38.
- Gazeta, G. S., Norberg, A. N., Aboud Dutra, A. E. & Serra Freire, N. M.** (2000) *Tyrophagus putrescentiae* (Schrank, 1781) as a vector of pathogenic bacteria: laboratory observation. *Entomologia Y Vectors* 7, 49-59.
- Guerra, A. A., Wolfenbarger, D. A. & Garcia, R. D.** (1972) Factors affecting reproduction of the tobacco budworm in the laboratory. *Journal of Economic Entomology* 58, 544-548.
- Hubert, J., Jarosik, V., Mourek, J., Kubatova, A. & Zdarkova, E.** (2004) Astigmatid mite growth and fungi preference (Acari: Acaridida): comparisons in laboratory experiments. *Pedobiologia* 48, 205-214.

- Hurtado, I. & Parini, M.** (1987) House dust mites in Caracas, Venezuela. *Annals of Allergy* 59, 128-130.
- Kasuga, S. & Amano, H.** (2000) Influence of temperature on the life history parameters of *Tyrophagus similis* Volgin (Acari: Acaridae). *Applied Entomology and Zoology* 35, 237-244.
- Korsgaard, J., Dahl, R., Iversen, M. & Hallas, T.** (1985) Storage mites as a cause of bronchial asthma in Denmark. *Allergology et Immunopathology* 13, 143-149.
- Kronqvist, M., Johansson, E., Magnusson, C. G. M., Olsson, S., Eriksson, T. L. J., Gafvelin, G. & Van Hage Hamsten, M.** (2000) Skin prick test and serological analysis with recombinant group 2 allergens of the dust mites *L. destructor* and *T. putrescentiae*. *Clinical and Experimental Allergy* 30, 670-676.
- Mecan, K. B., Mecan, J., Buneta, L. & Kraus, M. S.** (2000) Sensitization to non-pyroglyphid mites in urban populations of Croatia. *Croatian Medical Journal* 41, 54-57.
- Okabe, K., Miyazaki, K. & Yamamoto, H.** (2001) Population increase in mushroom pest mites on cultivated *Hypozygus marmoreus* and their vectoring of weed fungi between mushroom cultivation media. *Japanese Journal of Applied Entomology and Zoology* 45, 75-81.
- Papadopoulus, N., Katsoyannos, B & Carey, J.** (2002) Demographic parameters of the Mediterranean fruit fly (Dip: Tephritidae) reared in apples. *Annals of Entomological Society of America* 95, 564-569.
- Rack, G.** (1984) Systematics, morphology and biology of mites (Acari) in houses and stores and mites of medical importance. Part III. The mould mite *Tyrophagus putrescentiae* (Schrank, 1781) and other mites occurring in large numbers in new buildings. *Der Praktische Schädlingsbekämpfer* 36, 3-16.
- Sanchez Ramos, I. & Castanera, P.** (2001) Development and survival of *Tyrophagus putrescentiae* (Acari: Acaridae) at constant temperatures. *Environmental Entomology* 30, 1082-1089.
- Sinha, R. N.** (1964) Ecological relationships of stored product mites and seed-borne fungi. *Acarologia* 5, 372-389.
- Smarz, J. & Catska, V.** (1987) Food selection of the field population of *Tyrophagus putrescentiae* (Schrank) (Acari, Acarida). *Journal of Applied Entomology* 104, 329-335.

- Smarz, J.** (2003) Microanatomical and biological aspects of bacterial association in *Tyrophagus putrescentiae* (Acari: Acaridida). *Experimental and Applied Acarology* 31, 105-113.
- Solarz, K. & Solarz, D.** (1996) The allergenic mites in coal mine dust from coal mines in upper Silesia (Poland). *Annals of Agricultural and Environmental Medicine* 3, 49-55.
- Thind, B. B. & Dunn, J. A.** (2002) A laboratory evaluation of a regulated airflow through wheat at four combinations of temperature and humidity on the productivity of three species of stored product mites. *Experimental and Applied Acarology* 27, 89-102.
- Van Hage-Hamsten, M., Johansson, S. G. O., Høglund, S., Tüll, P. & Zetterstrom, O.** (1987) Occurrence of allergy to storage mites and IgE antibodies to pollens in a Swedish farming population. *European Journal of Respiratory Diseases* 71, 52-59.
- Walia, K. K. & Mathur, S.** (1995) Predatory behaviour of two nematophagous mites, *Tyrophagus putrescentiae* and *Hypoaspis calcuttaensis*, on root-knot nematode, *Meloidogyne javanica*. *Nematologia Mediterranea* 23, 255-261.
- Walter, D. E., Hudgens, R. A. & Freckman, D. W.** (1986) Consumption of nematodes by fungivorous mites, *Tyrophagus* spp. (Acarina: Astigmata: Acaridae). *Oecologia* 70, 357-361.

*Received:* 7 June 2005

*Accepted:* 6 June 2006