

Seasonal Abundance and Vertical Distribution of Mites in Flat Storage Containing Wheat

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The present study was carried out in a flat storeroom in central Greece, filled with approximately 60 tons of newly harvested wheat, in order to evaluate the population dynamics of stored-product mites and their predators in connection with horizontal and vertical distribution. At 15-day intervals, from July 2000 until March 2001, three replicates were taken from each sampling point at depths of 0–40, 40–80 and 80–120 cm, with a partitioned grain trier. The sampling points were divided into two zones, namely, central and peripheral. Air temperature, relative humidity, grain moisture and grain temperature were recorded during the sampling period. Twenty-four mite taxa were found, the dominant species being *Tyrophagus putrescentiae* (Schrank) and *Acaropsis docta* (Berlese). The numbers of these species varied significantly in the two zones and at the three depths. More individuals were found in the center compared with the periphery of the wheat bulk, and at the surface of the bulk than at greater depths. The highest mite population densities for the total mite species were recorded during October–November and after the middle of January.

KEY WORDS: Stored-product mites; seasonal abundance; distribution; *Acaropsis docta*; *Tyrophagus putrescentiae*; *Caloglyphus berlesei*; *Cheyletus polymorphus*.

INTRODUCTION

The importance of storage mites is often underestimated due to the small size of the mites, which makes it difficult to recognize infestations. However, the study of mite populations in stored commodities is important because mites damage the produce directly (30). It is well established that stored-product mites can be very harmful pests (11,20,26,28). They are able to complete their life cycle more rapidly than insects, produce more offspring and tolerate lower temperatures. The presence of storage mites in grain bulks poses a potentially serious threat to grain quality. The mites cause a loss in weight of the grain due to their feeding on it and downgrade it with the musty odor from their lipoid secretions. The grain becomes useless for seed (33) or brewing purposes and unacceptable for milling (30). In addition, mites cause illnesses in animals and man by carrying fungi externally and internally that produce mycotoxins and by causing dust allergy and intestinal disorders (28). They are vectors of allergens causing asthma, rhinitis and eczema, particularly in the occupational environment (7,9,17).

Storage ecosystems are complex and it is often difficult to comprehend their spatial / temporal dynamics (25). Various combinations of cultural, physical and biological methods can be implemented to control pests. Such methods depend on understanding storage ecosystems, including pest population dynamics and methods for accurate monitoring

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of pest population levels. Knowledge of the distribution of pests in storerooms is important from the point of view of their ecology as well as their control (3,8,34). It is therefore important to analyze the influence of various abiotic and biotic factors including temperature, relative humidity, moisture content, grain temperature, species density and predator-prey interaction affecting these populations (5,27). Most data available for spatio-temporal distribution of pest populations in stored products are about insects, whereas information on mites is still inadequate.

The purpose of the present project was to obtain information about the dispersion, distribution and seasonal changes in mite populations in bulked wheat stored in a horizontal-type facility. This knowledge is essential for accurate analysis and understanding of the structure and function of grain bulk ecosystems.

MATERIALS AND METHODS

The study was carried out in a $\sim 40\text{ m}^2$ horizontal-type (flat) brick-walled storeroom with a concrete floor located in central Greece (Oropos, county of Attiki). The storeroom has two windows covered with wire mesh and one wooden door which is kept closed. The storeroom, which is used only for wheat storage, had been empty since March 2000. In May 2000 the room was thoroughly cleaned. In June 2000 it was filled with approximately 60 tons of newly harvested durum wheat (var. 'Mexa'). From July 23, 2000 until March 14, 2001, when the grain was removed, wheat samples were taken at approximately 15-day intervals. Thus, there were 17 sampling occasions (dates), on each of which 39 samples were taken, totaling 663 samples. Samplings were carried out with a partitioned grain trier (1.60 m in length, nine openings, 60 g capacity per opening) from the 13 sampling locations shown in Figure 1. These locations were divided into two zones. The 'central zone' was defined as the central part of the grain mass (sampling points 1–5 in Fig. 1), whereas the 'peripheral zone' was defined as the part of the bulk which was close to the walls (sampling points 6–13 in Fig. 1). On each sampling occasion, three trier samples were taken from each location. The first sample was taken at a depth of 0–40 cm (top), the second sample at 40–80 cm (middle) and the third at 80–120 cm (bottom), corresponding to the upper, middle and bottom openings of the grain sampler. The moisture content of each sample was immediately determined with a moisture meter (grain digital tester, Moisture Master, Farmex, Streetsboro, OH, USA). At each sampling location the grain temperature was measured with a digital probe thermometer (TFA-Germany, Bremen, Germany) just below the grain surface and at depths of 30–40 and 50–60 cm. Additionally, the temperature and relative humidity of the storeroom were measured with a thermo-hygrograph (HOB0 H8, Data Logger, Onset Computer Co., Pocasset, MA, USA). No pesticides were applied during the sampling period.

A modified Berlese-Tullgren method (12,14) was used to extract the mites from the wheat samples. The extraction apparatus consisted of 36 funnels aligned on special shelves, with each funnel under a 35W light bulb. The heat from the light bulbs desiccated the grain and thus forced the mites downwards and eventually into a vial suspended beneath the funnel. The samples were left in the funnels for 5 days. The mites were identified using a compound research microscope. The taxa found were described using the criteria of Dominance and Frequency (10–13; Emmanouel, N.G. (1977) Ph.D. thesis, National University of Ireland). 'Dominance' indicates the percentage of individuals of a given taxon, compared with the total number of individuals of all taxa found. A

particular taxon can be classified as 'Dominant' (>10%), 'Influent' (5–10%) or 'Recedent' (<5%). Similarly, three categories are recognized for the 'Frequency' of occurrence of a taxon. Thus, a taxon can be classified as 'Constant' (>50%), 'Accessory' (25–50%) or 'Accidental' (<25%).

The JMP IN statistical package (23) was used for the statistical analysis. For the most abundant species, data were analyzed using a two-way analysis of variance to determine the influence of main effects (depth and zone) and interaction. Finally, for grain moisture content and grain temperature, data were analyzed using a one-way analysis of variance in order to determine differences among sampling dates, depths and zones. Means were separated using the Tukey-Kramer (HSD) test, at $P=0.05$ (29).

RESULTS

The relative humidity gradually increased from July 2000 to the end of January 2001, when it started to decrease (Fig. 2), whereas the temperature in the storeroom followed the opposite trend, ranging from 29°C in July to 10°C in December. For the whole study period, significant differences were recorded for grain temperature among sampling dates ($F=827.45$, $df=16$, 646 , $P<0.0001$). Similarly, significant differences were noted between two of the three depths examined (grain surface and 50 cm depth) ($F=3.13$, $df=2$, 660 , $P=0.0443$) (Fig. 3). The lowest temperatures were measured in the surface layer of the grain; at the two other depths the temperatures were more constant. Correspondingly, significant differences for grain temperature were noted between the two sampling zones ($t=2.65$, $df=1$, 661 , $P=0.0081$) (Fig. 4). The central zone was the warmest part of the bulk, by an average of 2.2°C compared with the peripheral zone, which is in accordance with the results recorded by Armitage (2) for unaerated bins filled with rapeseed. Generally, the mean grain temperature decreased gradually during the sampling period, except during the last three sampling occasions, when the temperature started to increase again.

Significant differences were noted in the grain moisture values among sampling dates ($F=12.13$, $df=16$, 646 , $P<0.0001$) and among the three depths ($F=147.93$, $df=2$, 660 , $P<0.0001$) (Fig. 5). The highest grain moisture was recorded at the top of the grain mass, and the lowest at the bottom (80–120 cm depth) during the experimental period. Significant differences were also recorded for grain moisture content among sampling zones ($t=4.92$, $df=1$, 661 , $P<0.0001$) (Fig. 6).

During the survey, a total of 4449 mite individuals were found, representing 24 taxa. Most of them are serious pests of stored grain [*Tyrophagus putrescentiae* (Schrank), *Acarus siro* L.], others are predatory mites [*Acaropsis docta* (Berlese), *Cheyletus malaccensis* Oudemans, *Cheyletus polymorphus* Volgin, *Blattisocius keegani* Fox, *Blattisocius tarsalis* (Berlese)], and other species may cause dust allergy and dermatitis [*Lepidoglyphus destructor* (Schrank), *Glyciphagus domesticus* (De Geer), *Dermatophagoides farinae* Hughes]. Moreover, the species *L. destructor* may be used as a bioindicator of spoilage of grain (27). Members of the Tetranychidae and Tydeidae families were extremely scarce and they are considered to be intruders. According to the criteria of dominance and frequency, the mite *T. putrescentiae* was found to be dominant and constant and the mite *A. docta* was dominant and accessory (Table 1). The most abundant species – *T. putrescentiae* and *A. docta* – represent more than 73% of the total number of mite individuals found. The mite *Caloglyphus berlesei* (Michael) is recorded for the first time in Greek stored products and the predator *C. polymorphus* is recorded for the first time in Greek mite fauna.

TABLE 1. Dominance and frequency of selected mite taxa

Mites taxa	% of total mites	Dominance	% of trier samples	Frequency
Astigmata				
<i>Tyrophagus putrescentiae</i> (Schrank)	42.99	Dominant	52.18	Constant
<i>Acarus sirol.</i>	0.63	Recedent	1.05	Accidental
<i>Lepidoglyphus destructor</i> (Schrank)	1.53	Recedent	1.80	Accidental
<i>Glycyphagus domesticus</i> (De Geer)	9.35	Influent	3.31	Accidental
<i>Caloglyphus berlesei</i> (Michael)	2.04	Recedent	2.11	Accidental
<i>Dermatophagoides farinae</i> Hughes	0.09	Recedent	0.15	Accidental
Prostigmata				
<i>Acaropsis docta</i> (Berlese)	30.81	Dominant	28.95	Accessory
<i>Cheyletus malaccensis</i> Oudemans	0.09	Recedent	0.15	Accidental
<i>Cheyletus polymorphus</i> Volgin	0.09	Recedent	0.15	Accidental
<i>Tarsonemus granarius</i> Lindquist	0.87	Recedent	0.90	Accidental
<i>Tarsonemus waitei</i> Banks	1.71	Recedent	1.96	Accidental
<i>Lorryia</i> sp.	0.72	Recedent	0.45	Accidental
<i>Tydeus</i> sp.	0.72	Recedent	0.90	Accidental
<i>Acarophenax</i> sp.	0.18	Recedent	0.30	Accidental
Tetranychidae	0.27	Recedent	0.45	Accidental
Pygmephoridae	0.40	Recedent	0.60	Accidental
Bdellidae	0.09	Recedent	0.15	Accidental
Calligonelidae	0.20	Recedent	0.30	Accidental
Mesostigmata				
<i>Blattisocius keegani</i> Fox	0.49	Recedent	0.75	Accidental
<i>Blattisocius tarsalis</i> (Berlese)	0.18	Recedent	0.30	Accidental
<i>Proctolaelaps</i> sp.	5.12	Influent	0.45	Accidental
Ameroseiidae	0.18	Recedent	0.30	Accidental
Cryptostigmata				
<i>Haplochthonius</i> sp.	0.24	Recedent	0.45	Accidental
Other Cryptostigmata	0.47	Recedent	0.60	Accidental

TABLE 2. Anova statistics for main effects and interaction for the most abundant species, *Tyrophagus putrescentiae* and *Acaropsis docta*

Species	Zone (df=1, 657)		Depth (df=2, 657)		Zone*Depth (df=2, 657)	
	F	P	F	P	F	P
<i>T. putrescentiae</i>	53.53	<0.0001	14.12	<0.0001	18.01	<0.0001
<i>A. docta</i>	29.67	<0.0001	5.53	0.0041	0.66	0.5162

TABLE 3. Mean number of individuals per sample ($\pm$ S.E.) for the most abundant mite species, *Tyrophagus putrescentiae* and *Acaropsis docta*, in each of the two sampling zones and at each sampling depth (means followed by a common letter do not differ significantly; Tukey-Kramer HSD test, $P=0.05$)

Species	Central zone	Peripheral zone	Sampling depth		
			Top	Middle	Bottom
<i>T. putrescentiae</i>	4.4 $\pm$ 0.22 a	2.68 $\pm$ 0.13 b	4 $\pm$ 0.25 a	3.05 $\pm$ 0.18 b	2.98 $\pm$ 0.18 b
<i>A. docta</i>	3.21 $\pm$ 0.32 a	1.34 $\pm$ 0.18 b	2.66 $\pm$ 0.31 a	2.21 $\pm$ 0.32 ab	1.32 $\pm$ 0.23 b

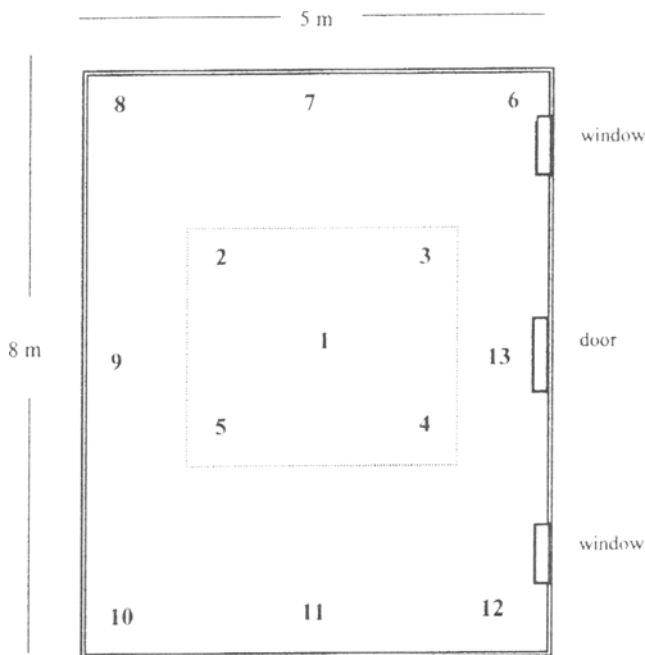


Fig. 1. Diagram of sampling locations in the storeroom.

The mite fauna in the grain peaked during October – November and after the middle of January. The presence of *T. putrescentiae* was relatively low during summer and September (<2.5 individuals per sampling date) (Fig. 7). However, after the middle of November the population of *T. putrescentiae* increased to >6.5 individuals per sampling date. After this peak, a noticeable decline was recorded until the end of the sampling period. There was a significant correlation of 0.63 between the relative humidity and the proportion of the population of the mite *T. putrescentiae* during the sampling period. The predatory mite *A. docta* was found in very low numbers (one individual per sampling date) early in the sampling period, but peaked during October and November (more than six individuals per sampling date) and rapidly declined again.

For the most abundant mite species, significant differences were noted between the two sampling zones (Table 2). Populations of *T. putrescentiae* and *A. docta* were higher in the central zone than in the peripheral zone (Table 3). Moreover, significant differences were recorded among the three depths examined (Table 2). Both *T. putrescentiae* and *A. docta* were present in all three layers but their numbers were highest in the top layer (Table 3). The populations of these two species follow the patterns which are presented in Figure 8. Finally, the interaction zone * depth was significant only for *T. putrescentiae* (Table 2).

DISCUSSION

During most of the experimental period the mean relative humidity was $>60\%$. However, the moisture content values were not optimal for development and reproduction of most stored-product mites. Apart from relative humidity, temperature is one of the main factors governing the abundance of mite populations (24). The air temperature range

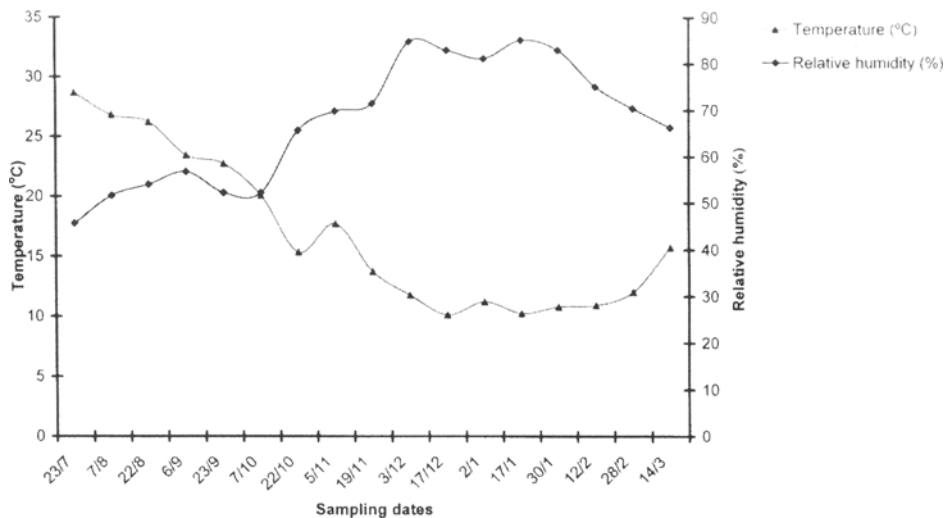


Fig. 2. Mean air temperature (°C) and relative humidity (%) during the sampling period (day/month).

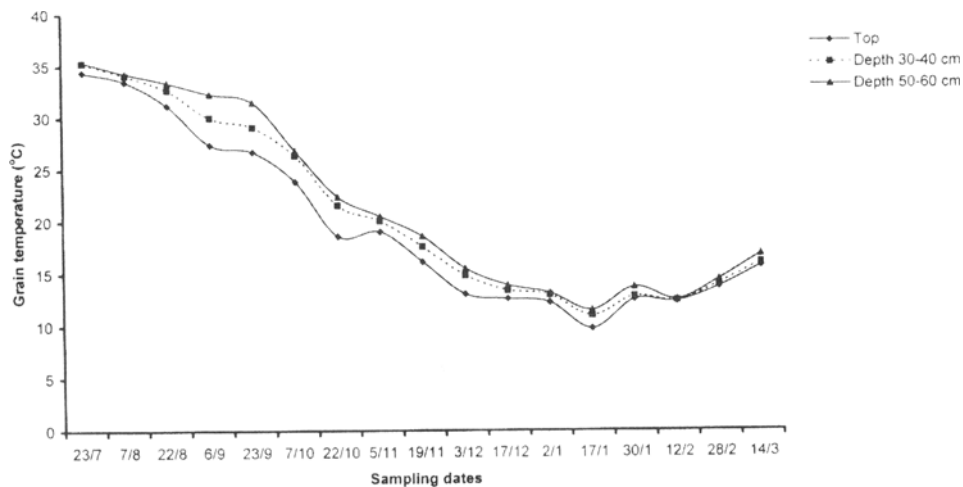


Fig. 3. Mean grain temperature (°C), at three depths, during the sampling period (day/month).

which was recorded (from 29°C in July to 10°C in December) is suitable for survival, development and multiplication of most species of stored-product mites (16,24,32). The concentration of *T. putrescentiae* rose with increasing relative humidity. The humidity has a direct influence on the rate of increase of this mite by affecting its development, survival and fecundity, and an indirect influence by affecting mold growth (21). Mites

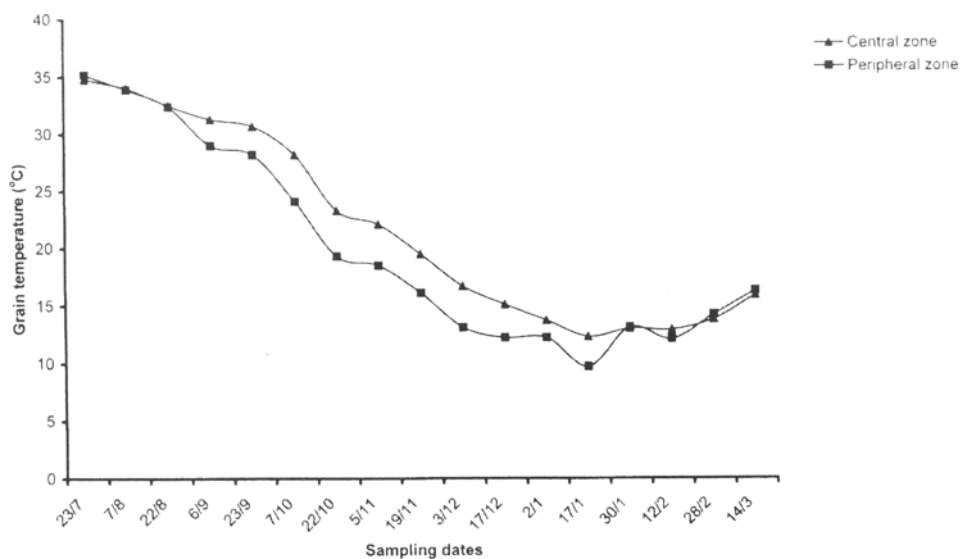


Fig. 4. Mean grain temperature (°C), in each sampling zone, during the sampling period (day/month).

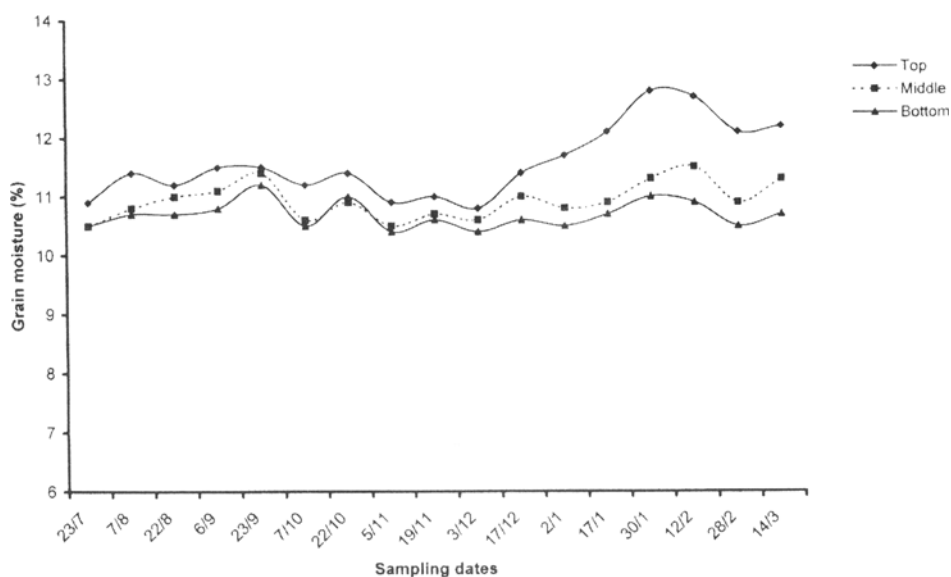


Fig. 5. Mean grain moisture content (%), at each sampling depth, during the sampling period (day/month).

which belong to the order Astigmata do not have respiratory stigmal openings, and respiration takes place through the cuticle. Thus, Astigmata are more sensitive at lower than higher relative humidity. The relative humidity is more important than the moisture

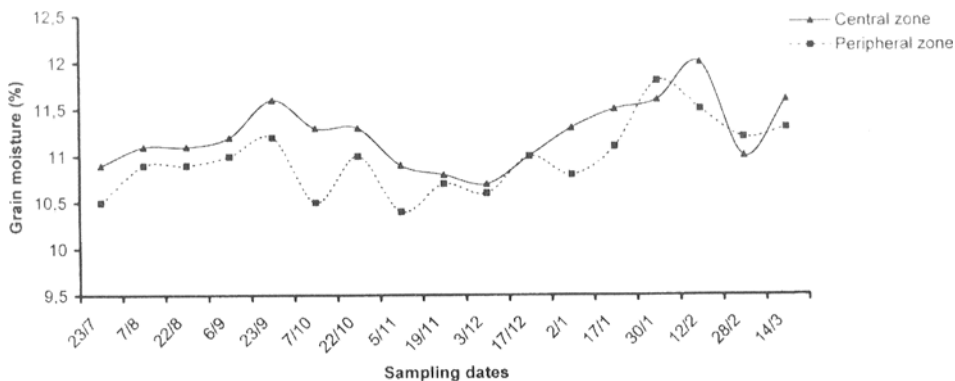


Fig. 6. Mean grain moisture content (%), in each sampling zone, during the sampling period (day/month).

content, as it measures the availability of water to micro-organisms and hence gives an indication of the biological activity, or potential activity, of the product (6). For instance, >75% r.h., molds will develop rapidly during storage, and heating of the product will occur, with subsequent deterioration and loss. Moreover, the grain moisture was higher in the central zone, compared with the peripheral zone, which is in accordance with the results of Hagstrum (15) for steel bins. Apart from that, the increase in moisture was more vigorous in the upper layer of the bulk, and less so in the deeper portion. This observation is in accordance with previous results in bulked grain (4). Mites of stored products tend to remain in locations with high moisture. Higher numbers of *T. putrescentiae* and *A. docta* in the central zone may be attributed to higher moisture contents and grain temperatures in this part of the bulk.

It is a common belief that irregular fluctuations are more the rule than the exception among stored-product mites (28). This implies that the controlling factors are complex. However, it is important to know whether or not the predator and prey will remain in the same vicinity, and whether or not one or the other is likely to move to other areas. As regards *T. putrescentiae*, more than 40% of the individuals were found in the top of the bulk on most of the sampling occasions. On the other hand, during the winter the highest proportion of *A. docta* was in the surface samples of the grain (top), whereas in summer *A. docta* was most common beneath the surface (middle sampling depth). Data concerning *A. docta* showed that this species follows a vertical migration from the lower to the upper layers of the wheat bulk during the experimental period. In the winter the surface of the grain was dampened by absorption of atmospheric moisture. Moreover, during cool weather the grain surface may become cooler than the underlying layers, producing convective air currents that pick up moisture from the warm grain and deposit it in cooler grain near the surface (19). Thus, the moisture content of the surface layers increased and mite individuals were most frequent there. These results are broadly similar to those found by Zdarkova *et al.* (34). In a recent study Athanassiou *et al.* (4) noted, in horizontally stored wheat, that the species *T. putrescentiae* was likewise found to be more abundant near the top of the bulk than at other depths. In the same study the predatory mite *Acaropsis sollers* Kuzin followed an almost similar population fluctuation pattern as *A. docta* in the present study.

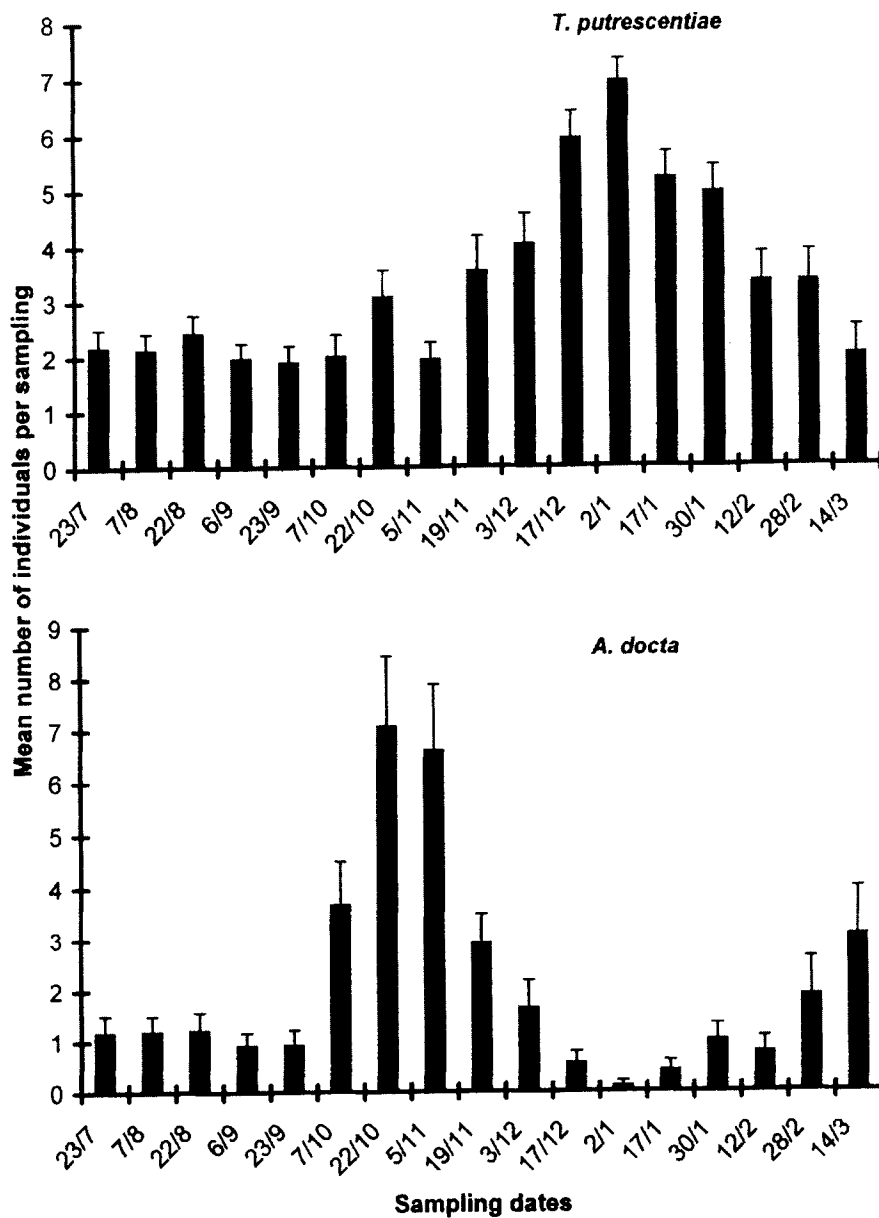


Fig. 7. Mean number of individuals per sample ($\pm$ S.E.), for the most abundant mite species, at each sampling date.

The highest numbers of *T. putrescentiae* were observed approximately 2 months after the peak of the predatory mite *A. docta*. The high or low incidence of *A. docta*, from season to season, is likely to influence the populations of *T. putrescentiae*. On the other hand, *A. docta* distribution could also be influenced by the occurrence of prey. Because

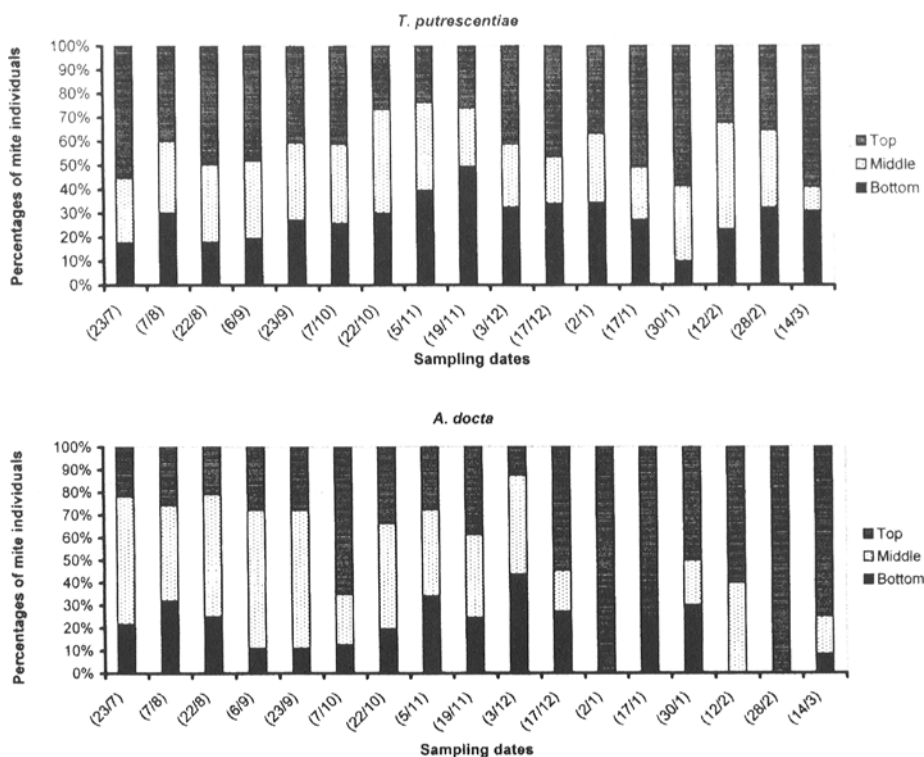


Fig. 8. Vertical distribution of the population of the most abundant mite species, and seasonal changes in this distribution.

A. docta is a predator, its wider dispersal can be considered as a part of prey-seeking behavior and location of isolated outbreaks of prey (34). Moreover, *A. docta* can also feed on beetle and moth eggs (1,18,22,31). Thus, the occurrence of insect eggs could also affect the distribution of this predatory mite. Finally, it is noteworthy that cannibalism is very common in this mite species even in the presence of host eggs (31).

Our results indicate that the predatory mites *A. docta* can interact with the acarid prey mites *T. putrescentiae* and may be an important limiting factor. It is the first time that this relationship has been recorded. *A. docta* is a possible potential biological control agent in stored-product ecosystems. The use of biological control in stored products has often met with the objection that, even if the pests were to be completely controlled by natural enemies, contamination would still be caused by the bodies of the latter. This problem occurs in storage and marketing systems where consumer tolerance to ‘impurities’ is extremely low. In tropical marketing systems, however, such fastidiousness is rare, and the low level of quality contamination caused by a successful natural enemy would be an enormous improvement over the serious losses caused by the pest. It is difficult to decide whether such considerations have played a role in the total lack of introductions of predacious mites into the stored-product habitat.

The conditions recorded in our study, especially grain moisture, did not permit the development of high mite densities (32). Hence, although some general trends can be

drawn, data from a given study may not be transferable to others. However, information on spatial distribution provided by this study can be used for future monitoring of grain mites. Further studies are required to understand the mechanisms of dispersion and distribution of the grain mites. This knowledge is important in order to avoid or minimize losses caused by stored-product mites.

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