Table 3. *Effect of heat treatment (30 min at 56°) on recovery from soil. Figures are averages from six replicate dilution plates*

	Ascospore germination (%) in:				Recovery from soil* (%)	
	PDB		CFU g^{-1} soil			
Isolate	Non-heated	Heated	Non-heated	Heated	Non-heated	Heated
TF1	2	80	2×10^4	$3{\cdot}5 \times 10^5$	5·9	103
TF2	4·4	91	1×10^4	$2{\cdot}6 \times 10^5$	3·3	87

* Ratio of CFU density to initial ascospore density in soil.

fertility) tend to produce some conidia in darkness. Conidia which adhere to harvested cleistothecia become inseparable contaminants of the ascospores, thus disturbing ascospore-progeny analysis. Because of differential sensitivity of ascospores and conidia, a heat treatment (30 min at 50°) would not only activate dormant ascospores but also eliminate contaminating conidia.

Activation of ascospores in heated soil presumably accounts for the observation that *T. flavus* can be isolated from soil using a hot-water treatment method but not otherwise (Boosalis, 1956). Such heat treatment might be used selectively to improve assessment of *T. flavus* populations in soil, and for studying its survival and proliferation. To what extent ascospore dormancy contributes to the survival capacity of *T. flavus* in soil remains to be determined.

This paper is contribution no. 1144-E (1984 series) from the ARO, Bet Dagan.

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USE OF SPOROTHECAE BY PHORETIC *TARSONEMUS* MITES TO TRANSPORT ASCOSPORES OF CONIFEROUS BLUESTAIN FUNGI

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Certain female *Tarsonemus* mites, like their host bark beetles, carry a specific fungus upon which the mites feed, inside a special morphological, spore-carrying structure called a sporotheca. The sporotheca is similar to the mycangium described for bark beetles, but differs in that no gland cells are present and the fungal spores do not multiply in the structure. So far, the phenomenon has been observed only in North America and China where the phoretic hosts of the mites are *Dendroctonus* and *Ips*.

The term sporotheca was first used by Suski (1973) to describe paired eversible sac-like structures containing spores found behind coxa II of two species of female *Siteroptes*. Suski noted that the spores were probably conidia of *Fusarium poae* (Peck) Wollenw., a grass pathogen with which the two *Siteroptes* were associated. A third species of *Siteroptes*, also associated with the fungal disease, did not possess the sporotheca.

Two more types of sporothecae have apparently evolved independently in females of the genera *Siteroptes* and *Trochometridium* which belong to the closely related mite families Pygmephoridae and Pyemotidae, both of which belong to the subcohort Heterostigmae. *Trochometridium tribulatum* Cross has sporothecae openings on coxal plates IV; Alfaro (1946) describes another sporotheca for a species of *Siteroptes* which carries one or two conidia of *Nigrospora oryzae* (Berk. & Br.) Petch, which causes lint rot of cotton. This type of sporotheca forms a pouch on the hysterosoma just behind the fourth pair of legs. Again, the mite and fungus are associated and the fungus is pathogenic to the plant. The *Siteroptes* feed on the mycelia of *N. oryzae*, which is required for the mite's normal growth and reproduction (Laemmlen & Hall, 1973).

Most bluestain diseases of conifers caused by *Ceratocystis* spp. are carried by scolytid beetles (Upadhyay, 1981). Although Leach, Orr & Christensen (1934), Hetrick (1949), and Moser, Wilkinson & Clark (1974) suspected that mites phoretic on these bark beetles might carry spores of *Ceratocystis* spp., Bridges & Moser (1983) were the first to provide good evidence. They reported that *Ceratocystis minor* (Hedgcock) Hunt associated with the southern pine beetle, *Dendroctonus frontalis* Zimmerman, is hypervectored by two species of phoretic female mites of the family Tarsonemidae, subcohort Heterostigmae. Both mites (*Tarsonemus ips* Lindquist and *T. krantzi* Smiley & Moser) feed on *C. minor* and move from areas of fungus-colonized bark to cracks in the outer bark where they attach to emerging adult beetles (Roton, 1978). This report concerns mites carrying bluestain ascospores in a fourth type of sporotheca.

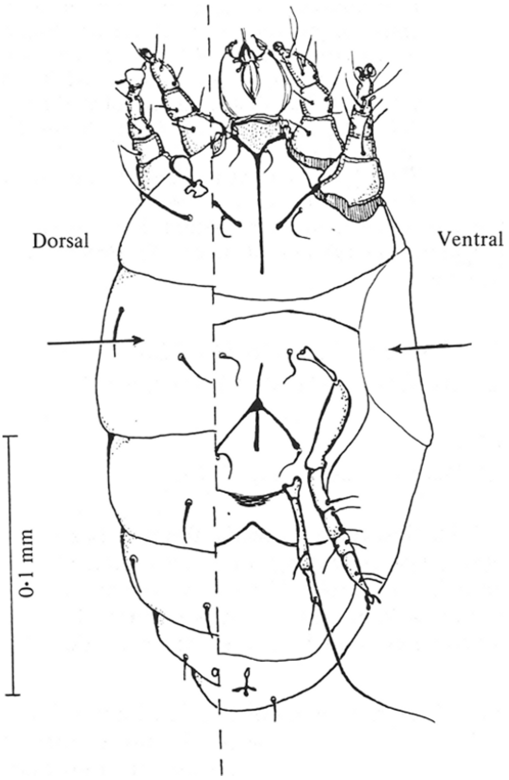

Fig. 1. Female of *Tarsonemus ips* showing the location of tergite 1 (arrows).

Several thousand mites have been microscopically examined for the presence of *C. minor* ascospores on the 15 mite species that are commonly phoretic on *Dendroctonus frontalis*, which attacks *Pinus* spp. in the southern United States.

Tarsonemus mites have also been scanned from adults of at least 50 other species of Scolytidae reared or trapped from various trees (mostly conifers) around the world.

The mites were mounted on slides and examined microscopically for *Ceratocystis* ascospores, and, if positive, whether they were concentrated on certain body surface areas of the mites.

Ascospores were abundant on body surfaces on individuals of all mite species removed from fruiting colonies of *C. minor* under bark (Bridges & Moser, 1983). However, *Tarsonemus ips* and *T. krantzi* were the only mites that carried ascospores in the phoretic state on *D. frontalis*.

The number of ascospores varied from 1 to over 100 on *Tarsonemus* mites, but they were usually located under one or both sides of tergite 1 (Fig. 1). The area under tergite 1 contains no unique morphological features to hold the spores and looks like the tergite 1 of other non-spore carrying species of *Tarsonemus*. But, functionally, the structure appears to fit the definition of a sporotheca as defined by Suski (1973) as 'paired external sacs used to transport fungal spores'. But this system is more primitive than those described for *Siteroptes* and *Trochometridium*, because in *Tarsonemus* a unique morphological structure for carrying the spores never evolved.

The sporotheca is similar to the mycangium of scolytid beetles defined by Batra (1963) except that a sporotheca does not contain glands to nourish the fungi, and the fungi do not multiply within the sac.

Upadhyay (1981) splits the genus *Ceratocystis* into four sections: *Ips*, *Ceratocystis*, *Endoconidiophora*, and *Ophiostoma*. Because the ascospores of each have distinctive shapes, they can often be identified to section by viewing them microscopically. *C. minor* belongs to section *Ophiostoma*, the spores of which are often thin and crescent-shaped. Ascospores of *C. minor* and other species of *Ophiostoma* were almost always located in sporothecae of phoretic *Tarsonemus* mites; only rarely were these ascospores seen in a random fashion on

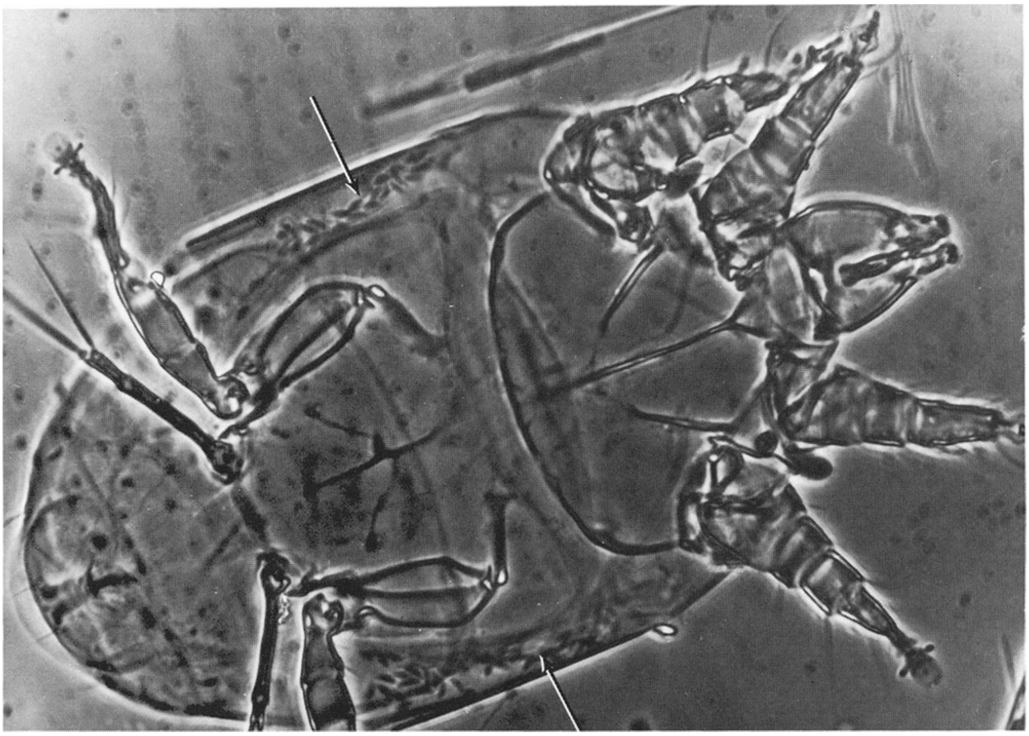

Fig. 2. Ventral surface of *Tarsonemus ips* female phoretic on *Dendroctonus frontalis* from *Pinus taeda*, Louisiana. Note the numerous ascospores of *Ceratocystis minor* in sporothecae (arrows) formed by tergite 1 on lateral sides of the mite.

body surfaces of *Tarsonemus* and other phoretic mites. Ascospores of all of the other sections except *Endoconidiophora* were seen on the body surfaces of various phoretic mites, but none occurred under tergite 1 on any *Tarsonemus* or in structures that might be construed as sporothecae in other mites (Moser, unpubl.).

Crescent-shaped *Ophiostoma* ascospores in *Tarsonemus* sporothecae have been seen from localities other than Louisiana (Fig. 2). All were morphologically similar or identical to those of *C. minor*, but all were seen on mites that had been preserved in alcohol. For this reason their identities could not be confirmed by culturing. Hence, the following *Ceratocystis* names are speculative, based on literature references following most records: (1) *Ceratocystis minor* on *Tarsonemus krantzi* phoretic on *Dendroctonus frontalis* from *Pinus leiophylla* Schiede, Puebla, Mexico (Bridges & Moser, 1983); (2) *Ceratocystis minor* on *Tarsonemus krantzi* on *Dendroctonus frontalis* from *Pinus oocarpa* Schiede, Cedros, Honduras (Bridges & Moser, 1983); (3) *Ceratocystis minor* and/or *C. nigrocarpa* Davidson on *Tarsonemus endophloeus* Lindquist and *T. ips* phoretic on *Dendroctonus brevicomis* LeConte from *Pinus ponderosa* Douglas ex Lawson, Bass Lake, California (Whitney, 1982); (4) *Ceratocystis minor* and/or *C. nigrocarpa* on *Tarsonemus* prob. n.sp. nr *endophloeus* phoretic on *Dendroctonus pseudotsugae* Hopkins from *Pseudotsuga menziesii* (Mirbel) Franco, Moscow, Idaho (Upadhyay, 1981); (5) *Ceratocystis minor* and/or *C. nigrocarpa* on *Tarsonemus* prob. *endophloeus* phoretic on *Ips paraconfusus* Lanier from *Pinus coulteri* D. Don, Lake Arrowhead, California; (6) *Ceratocystis piceae* (Munch) Bakshi on *Tarsonemus* n.sp. nr *endophloeus* phoretic on *Ips nitidis* Eggers from *Picea asperata* Masters, Ginsu Provence, China (H. P. Upadhyay, pers. comm., agrees that *piceae* may be this species of *Ceratocystis*) (Fig. 3). Thus the sporothecae that

Fig. 3. Ventral surface of *Tarsonemus* n.sp. nr *endophloeus* female phoretic on *Ips nitidis* from *Picea asperata*, Ginsu Provence, China. Note the 61 ascospores of *Ceratocystis* sp. in sporothecae (arrow) formed by tergite 1 on lateral sides of the mite.

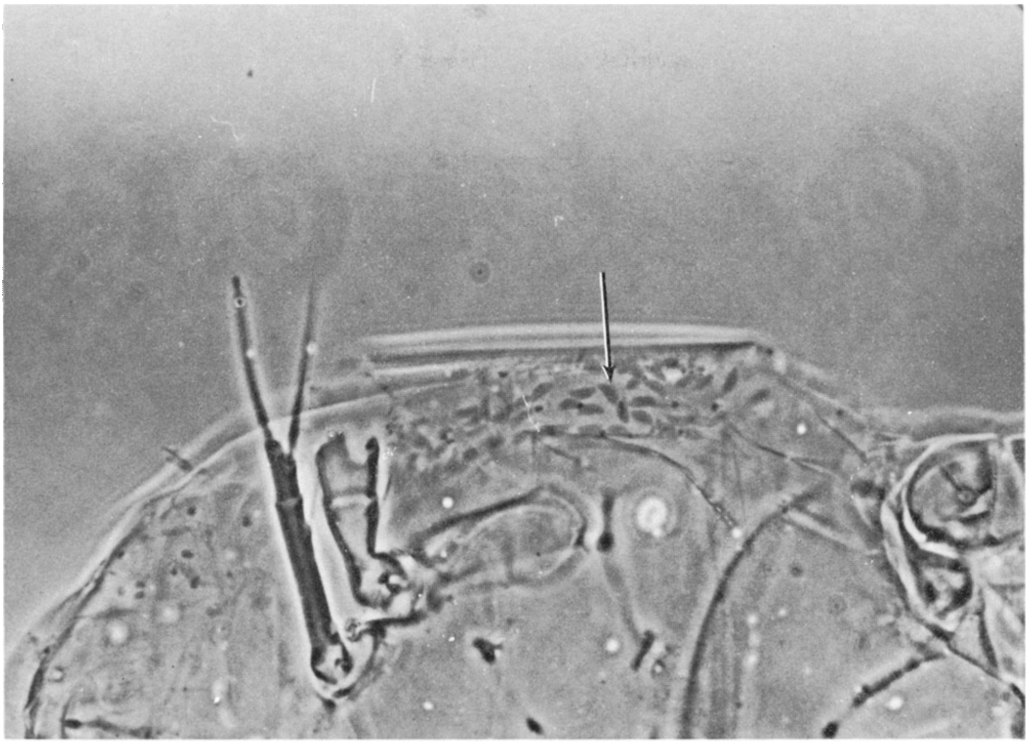

Fig. 3. For caption see opposite.

carry *Ceratocystis* ascospores on conifers are found on just a few species of *Tarsonemus*, but are associated with at least two genera of bark beetles on a rather broad range of host trees, and the phenomenon may be widespread geographically.

I wish to thank E. E. Lindquist and R. N. Sinha for helpful discussions, D. Barstow, J. H. Cain, J. F. Coyne, W. E. Rose, P. E. Tilden, and H.-f. Yin, for collection of bark beetles which contained the mites, and G. W. Krantz and H. P. Upadhyay for reviewing the manuscript.

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