# Insects and other arthropods as agents of vector-dispersal in fungi

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## INTRODUCTION

*"Fungi cannot walk or run, but some can swim, most can soar, a few can jump, and some must be carried"* (Kendrick 1985).

Spores are the reproductive propagules of fungi, and the various modes of spore liberation and dissemination that are prevalent among different groups of fungi are critical for the success and survival of fungal species (Ingold 1953, 1965). Aerial (or anemophilous) dissemination of fungal spores is the primary means of dispersal for many fungi. Spores of many ascomycetes (ascospores) and basidiomycetes (basidiospores) are forcibly ejected from the fertile tissue of the fruiting bodies to reach the air currents. Additionally, many asexual spores of common molds (hyphomycetes) are produced in dry chains and easily become airborne. Other fungi, such as the aquatic hyphomycetes, produce spores that float and employ water as a means of dispersal. Of particular interest here are those fungi that utilize insects and other arthropods to move their spores from the site of growth and production to new substrata for colonization.

Insect-vectored spore dispersal is recognized in many groups of fungi, including ascomycetes, basidiomycetes, imperfect fungi and zygomycetes (Ingold 1953, Kendrick 1985), as well as in the myxomycetes or slime molds (Stephenson and Stempen 1994) [slime molds do not belong to the Kingdom Fungi]. A general distinction has been made between the dispersal methods of dry versus sticky or slimy spores. Dry spores are dispersed by air, while sticky or slimy spores rely on water or vector dispersal (Webster 1980). Morphological adaptations are similar in many groups and are the result of parallel coevolutionary forces (Cain 1972, Pirozynski and Hawksworth 1988). Adaptations in various fungal groups as a result of selection for arthropod dispersal are examined in more detail below.

### Macrofungi - Basidiomycetes

Several types of fungal fruiting bodies produce sticky masses of spores in a thick, slimy layer. The most prominent of these are the stinkhorns (e.g., *Phallus, Mutinus*). A strong fetid odor is produced to attract flies to land on the glebal surface to feed. Many spores adhere to the legs and bodies of the flies, and the insects may remove the entire slime layer, filled with basidiospores, within a few hours. The spores are dispersed to nearby sites visited by the flies and are excreted, relatively unaltered, by the insects (Ingold 1965). In general, fungi adapted to dispersal by flies tend to offer minute, smooth-walled spores in a sugary slime coating (Ingold 1953).

Beetles and other insects may also disperse macrofungi. The fruiting bodies of the wood-inhabiting polypore, *Crytoporus volvatus,* have a membrane covering most of the fertile, spore-producing layer. Although some spores reach the air for anemophilous dispersal, the majority of spores accumulate on the inner surface of the sheath and are disseminated by beetles, which forage within the fruiting body (Ingold 1953).

**Molds – Imperfect fungi with sticky spore masses**

A common adaptation among the hyphomycetes (filamentous microfungi or molds) is the production of asexual spores, or conidia, in slimy droplets. These sticky masses of spores adhere to the legs and bodies of a variety of arthropods as they move across a mold-contaminated surface.

Some molds will produce a large slimy droplet, often on the top of an elongated stalk. Molds such as *Graphium, Leptographium, Pesotum, Stilbella*, *Stachybotrys, Gliocladium,* and *Myrothecium* have complex conidiophores and employ this mode of dispersal (Abbott 2000, Ingold 1953, Seifert 1985, Upadhyay 1981, Wingfield et al. 1993). These large, complex structures arise vertically from the substratum, and are tall enough to contact large insects migrating over the surface. Other molds, including *Trichoderma, Acremonium, Gliomastix, Fusarium,* and *Verticillium,* produce large numbers of small droplets at the apex of simple conidiophores (Carmichael et al. 1980, Ingold 1953). The conidiophores are produced in various orientations throughout the mycelium, and are particularly effective in contacting small insects moving through a mycelial mass.

Spores of these molds typically have a slimy or mucilaginous coat, enabling them to adhere together in masses. Additionally, the spores are often surrounded by sugary secretions with attractive odors to entice insects (Webster 1980). The consistency and solubility of the slimy spore masses varies considerably among the various species, and ranges from extremely viscous to watery (Seifert 1985, Wingfield et al. 1993).

Various arthropods have been implicated in dispersal of different fungi. Bark beetles (e.g., *Dendroctonus, Ips*) are well known for their involvement with dispersal of sap-stain fungi, both the ascospores (see below) and the conidia of the imperfect stages (e.g.*, Leptographium, Pesotum*)(Upadhyay 1981, Wingfield et al. 1993). Other insects include flies, springtails and larval stages of various groups. Mites are also frequent colonizers of mold-contaminated substrata. Fungus mites (e.g., *Tyrophagus*) feed on the mycelium and spores. Fecal material, or frass, of insects and mites is often packed with fungal spores, often appearing intact and unaffected by passage through the arthropods (Abbott, unpublished data).

**Ascomycetes – Adaptations for insect dispersal**

Ascomycetes that rely upon insects for spore dispersal often exhibit a similar suite of features. Characters include loss of forcible spore discharge and evanescent asci, sticky ascospores, and long-necked perithecia (Cassar and Blackwell 1996). In many of these genera, the ascospores are extruded from the ascocarp neck in a droplet or sticky mass. The spore masses, called cirrhi, of genera such as *Microascus, Petriella,* and *Chaetomium* are long, sticky columns, resembling a squeezed tube of toothpaste. In these examples, dispersal is achieved in the same manner as described above for the sticky spored molds; i.e., adherence to arthropods moving throughout the fungus colonized substratum (Abbott 2000, Arx et al. 1986).

In the sap-stain fungi or lumber molds (Ophiostomatales), the fungi frequently colonize the wood in the galleries of bark beetles. Ascospores are formed in wet droplets at the flared apex of the perithecial necks in *Ophiostoma, Ceratocytis*, and *Sphaeronaemella*. The long necked ascocarps and long stalked conidiophores project into the insect passageways and effectively force the insects into contact with the spore masses as they pass through the restricted spaces (Upadhyay 1981, Wingfield et al. 1993).

Other ascomycetes employ insects in different ways. In some of the Onygenales (e.g., *Myxotrichum, Auxarthron, Gymnoascus*), the ascocarp peridium is composed of a mesh-like arrangement of thick-walled hyphae, and the structure is often ornamented with hooks and spines (Currah 1985). These attach to insects and other animals in much the same manner as plant burrs adhere to animal hair. As the insects move about, the spores are shaken out of the meshwork of the peridium and effectively disperse the ascospores to new substrata. In *Chaetomium*, the elaborately undulate, branched, hooked and coiled setae on the ascocarps may serve a similar function. The ascospores adhere in mass to the setae, and are dispersed by beetles, ants, mites and other animals (Arx et al. 1986).

**Dry spores and insects – The feather duster theory**

Some dry-spored molds may make use of insects in addition to air currents as a means of dispersal. The genus *Cephalotrichum* produces its spores in a dry head at the apex of a complex conidiophore or synnema. These synnemata are often up to a millimeter in height and are produced at right angles to the substratum surface (i.e., erect). The fused hyphae of the synnematal stalk provide resilience, and have been demonstrated to spring back into the upright condition when gently manipulated in the laboratory (Abbott 2000). As the insects move through the miniature forest of a sporulating colony and brush against the synnemata, small clouds of spores are released, effectively dusting the insect with spores. This contrasts with the ‘paint brush’ method employed by the slimy-spored synnemata of species such as *Graphium* (see above).

A similar strategy may be employed by some myxomycetes (slime molds). The dry spores of their reproductive stage may be produced in similar stalked structures (e.g., *Stemonitis*) and are dispersed by tiny slime mold beetles (e.g., *Anisotoma, Agathidium*), which live and feed in the fructifications (Stephenson and Stempen 1994).

**Unique insect-fungus interactions**

Many specific examples of coevolution between fungi and insects have been recorded. In some cases, the insects aid in the dispersal of plant pathogens. For example, smut spores may be carried from flower to flower by insect pollinators (Ingold 1953). Fungal pathogens of insects (e.g., Entomophorales) have also adapted to obtain eventual dispersal from one individual to others within the insect community (Pirozynski and Hawksworth 1988).

Mutualistic relations between insects and fungi are also known. Fungus gardens are cultivated by leaf-cutter ants (e.g., *Atta, Acromyrex*) in tropical and subtropical America. The ants carry and maintain a selected species of fungus (e.g., *Leucoagaricus*) to inoculate onto the piles of harvested leaf pieces in order to provide a food source for the larvae (Fisher et al. 1994, Wheeler 1907). Other fungi (e.g., *Termitomyces*) are associated with termites (e.g., *Termes*) in Africa and Asia (Wheeler 1907). Ambrosia beetles (e.g., *Xyleborus*) are bark borers that cultivate the ambrosia fungi (e.g., *Ambrosiella*) to feed both the larvae and adults. The ambrosia fungi are transported in specialized pouches called mycangia, and are an integral part of beetle brood galleries (Cassar and Blackwell 1996, Wheeler 1907).

## DISCUSSION

Vector dispersal by insects and other arthropods is a significant mode of dissemination of fungal spores. The prevalence of slimy spored molds on saturated or very wet building materials has been noted in a number of microbial surveys of buildings with a history of water intrusion. Species of particular prevalence include the molds *Stachybotrys, Acremonium, Fusarium*, and *Trichoderma*. Additionally, several ascomycetes that produce spores in slimy masses are common on building materials. The lumber molds *Ophiostoma* and *Ceratocystis* are common on wood used in construction, while *Chaetomium* and *Petriella* are frequently found on persistently wet wood and other cellulose containing substrata in indoor environments. The presence of arthropods including mites, springtails, beetles, ants, and fungus gnats has been observed on mold contaminated building surfaces. Their presence is also frequently inferred on surface samples by the presence of frass (Abbott, unpublished data).

Recently, the development of heat technology for thermal pest eradication has demonstrated a new potential for control of mold dissemination through control of insect vectors. Temperatures of 54 C (130 F) for 7 minutes are effective for 100% mortality of German cockroaches, flour beetles, drywood termites and Argentine ants, while treatment at 60 C (140 F) for 60 minutes is effective against house dust mites (Precision Environmental, Inc. 2001). Heat treatment will also kill fungal spores and vegetative structures (50-66 C for up to 75 minutes) and can substantially aid the rapid drying of building materials. Thus, the combined attributes of heat technology for control of mold growth and insect vectors of fungal spores may prove useful in the rapid resolution of moisture-related building problems.

## Literature Cited

Abbott, S.P. 2000. Holomorph studies of the Microascaceae. Ph.D. Thesis, University of Alberta Dept. of Biological Sciences, Edmonton, AB.
Arx, J.A. von, J. Guarro, and M.J. Figueras. 1986. The ascomycete genus *Chaetomium*. Beihefte zur Nova Hedwigia 84:1-162.
Cain, R.F. 1972. Evolution of the fungi. Mycologia 64:1-14.
Carmichael, J.W., W.B. Kencrick, I.L. Conners, and L. Sigler. 1980. Genera of hyphomycetes. University of Alberta Press, Edmonton, AB.
Cassar, S. and M. Blackwell. 1996. Convergent origins of ambrosia fungi. Mycologia 88:596-601.
Currah, R.S. 1985. Taxonomy of the Onygenales: Arthrodermataceae, Gymnoascaceae, Myxotrichaceae and Onygenaceae. Mycotaxon 24:1-216.
Fisher, P.J., D.J. Stradling, and D.N. Pegler. 1994. Leaf cutting ants, their fungus gardens and the formation of basidiomata of *Leucoagaricus gongylophorus*. Mycologist 8:128-131.
Kendrick, B. 1985. The fifth kingdom. Mycologue Publications, Waterloo, ON.
Ingold, C.T. 1953. Dispersal in fungi. Oxford University Press, London, UK.
Ingold, C.T. 1965. Spore liberation. Oxford University Press, London, UK.
Pirozynski, K.A. and D.L. Hawksowrth (eds.). 1988. Coevolution of fungi with plants and animals. Academic Press, London, UK.
Precision Environmental, Inc. 2001. Heat Eradication Chart. Precision Environmental, Inc., CA.
Seifert, K.A. 1985. A monograph of *Stilbella* and some allied hyphomycetes. Studies in Mycology 27:1-235.
Stephenson, S.L. and H. Stempen. 1994. Myxomycetes: a handbook of slime molds. Timber Press, Portland, OR.
Upadhyay, H.P. 1981. A monograph of *Ceratocystis* and *Ceratocystiopsis*. University of Georgia Press, Athens, GA.
Webster, J. 1980. Introduction to Fungi, 2$^{nd}$ ed. Cambridge University Press, Cambridge, UK.
Wheeler, W.M. 1907. The fungus growing ants of North America. Dover Reprint, New York.
Wingfield, M.J., K.A. Seifert and J.F. Weber (eds.). 1993. *Ceratocysitis* and *Ophiostoma* taxonomy, ecology, and pathogenicity. APS Press, St. Paul, MN.