Massospora Fungal Mind Control:
Sexual Excess in Infected Cicadas

Michael Beug
Professor Emeritus,
The Evergreen State College
P.O. Box 116, Husum, WA 98623
beugm@evergreen.edu

In early August of 2018 I received an email from Paul Stamets containing a link to an article by Ed Yong published in *The Atlantic* on July 30, 2018 titled "This parasite drugs its hosts with the psychedelic chemical in shrooms. It also makes their butts fall off." Immediately, a host of questions arose in my mind. Are people soon going to be seeking out infected cicadas in an effort to get high? What is *Massospora*? I thought about zombie ants and wondered if *Massospora* is an anamorphic ascomycete related to the Ophiocordycipitaceae? I looked up *Massospora* in Index Fungorum and found that there are 14 named species in the genus and that it is a zygomycete and not a member of the Ascomycota. The family is the Entomophthoraceae and there are 241 species and 14 genera currently recognized in the family. All known species in the family infect insects and other arthropods and many have been investigated as biocontrol agents, though none have been grown in culture. Examples include *Entomophthora muscae*, a fungus that infects flies, grows into their brains, and forces the flies to land and then crawl up as high as possible where the fly's mouthparts clamp down hard and the fly dies, soon to release its spores where other flies will be infected (see Tom Volk's Fungus of the Month for March 2000). Another species, *Entomophaga grylii*, attacks grasshoppers causing them to crawl to the top of plants and die with heads up and legs tightly wrapped on the stalks. As is the case with members of the Ophiocordycipitaceae, the fungus causes the victim to crawl to a high place in an area frequented by others of the same species, clamp down tightly and die, after which a fruiting body emerges to spread spores (as in the Ophiocordycipitaceae) or the abdomen ruptures releasing spores where other victims can be infected (as in the Entomophthoraceae). The general process is known as "summit disease" and allows the fungus to place itself as high as possible to spread its spores as widely as possible. *Eryniopsis lampyridium*, which infects the goldenrod soldier beetles, *Chauliognathus pensylvanicus* and *Chauliognathus marginatus*, goes the other species one better. It causes infected beetles to climb to the top of the flower, clamp its mandibles on the flower and then die, but at dawn 15 to 22 hours later, the wings open into a mating pose attracting other soldier beetles to attempt to mate, only to be exposed to infectious spores by then covering the abdomen of the initial victim. I did not find reference to any other fungal parasites like *Massospora* species that keep their host alive to help spread its spores.

Charles Horton Peck, New York State Botanist from 1867 to 1915, made 36,000 collections of fungi, mosses, ferns and seed plants during his famed career. Though not trained in mycology, he named 2,700 species of fungi. Possibly the strangest fungus that he named was *Massospora cicadina*. *Massospora cicadina* infects periodical cicadas. After 13 or 17 years living underground in the larval stage, adult periodical cicadas emerge from the ground in massive synchronized events for about a month of song and sex. Approximately 2-5% of the adult cicadas become infected with *M. cicadina* as they begin to emerge from the ground. In 2013, student Angie Macias wrote a fascinating post for Dr. Kathie Hodge's Cornell Mushroom Blog about these "flying saltshakers of death," so named because the infection causes the rear end of the cicada to drop off, and exposing a conidial spore plug. As the infected cicadas fly, spores rain down onto the ground where the spores will lie in wait for future mass emergences. There has long been interest in the potential to use *M. cicadina* as a biological control agent but mass cultivation of the fungus has failed. There has also long been interest in understanding how the fungus is able to consume the cicada while preserving its flight muscles and controlling its brain. In 2018, our knowledge of this fungal parasite exploded with the publication of two papers. In the first paper, John R. Cooley, David C. Marshall and Kathy B.R. Hill (2018) report on the life cycle and behavior of infected and uninfected periodical cicadas. They found that the fungal infection has two distinct stages. In stage I, as the cicada changes to the adult form, the associated chemical signals trigger resting spores of *Massospora cicadina* on the nymphs or in the soil to germinate on the emerging adult. The fungus proceeds to consume the infected cicada from the reproductive end forward, a process that takes about one week. The rear end of the cicada then falls off revealing a plug of haploid conidial spores. However, the fungus is slow to kill the cicada. The fungus takes control of the insect's brain, propelling the insect into a frenzy of sexual mating activity—except no gonads remain, only highly infective stage I spores are present to spread the infection to healthy cicadas. Furthermore, infected males not only crawl around spreading spores, but also engage in female wing-flick behavior attracting other males who attempt to mate thus directly infecting healthy males and initiating stage II infections. In the stage II infection, a different type of conidial spore is produced, a diploid, thick-walled resting spore. The stage II infected cicadas also soon lose their rear ends to the fungal infection. The stage II infection causes the cicadas to fly, raining resting spores onto the ground where the stage II spores will lie dormant until triggered to grow on a new generation of emerging cicadas.

A second paper, "Discovery of psychoactive plant and mushroom alkaloids in behavior-modifying fungal cicada pathogens" (Boyce, et al., 2018) announced the discovery of the

indole 4-hydroxytryptamine and the amphetamine cathinone in *Massospora cicadina*. Previously cathinone has only been found in the khat plant, *Catha edulis*, found in the Horn of Africa and in the Arabian Peninsula. The tradition of chewing khat leaves goes back thousands of years in that region. Cathinone causes excitement, loss of appetite and euphoria. Boyce et al. propose that the role in *M. cicadina* parasitism may be to make the doomed cicadas more active in spreading the fungal spores while not caring about their own fate. Boyce et al. also studied the chemistry of two other *Massospora* species, *M. platypediae* and *M. levispora*, which both parasitize annual cicadas. Annual cicadas live in the ground as larvae for one to nine years before emerging to mate as adults but differ from periodic cicadas in that they do not emerge in a coordinated manner. *Massospora platypedia* and *M. levispora* lacked cathinone but contained psilocybin and/or psilocin, psychedelic compounds known from about 200 species of Basidiomycota but never previously found elsewhere. *Massospora platypediae* also contained the psychedelic compounds baeocystin and norbaeocystin, known from the basidiomycete *Psilocybe cyanescens.*

You (and the Drug Enforcement Agency) may be interested in whether or not parasitized cicadas are candidates for consumption by humans seeking mind-altering effects. The cathinone levels found in *M. cicadina* varied from not detectable in 58% of the fungal plugs studied to a range of 44-300 ng/plug in 42% of the plugs. The effective cathinone dose for humans is estimated to be in the 30-60 mg range, equal to consuming anywhere from 200,000 to over 1,000,000 dead parasitized periodic cicadas. *Massospora cicadina* had no detectable psilocybin or psilocin. *Massospora platypediae,* which infects the wing-banger cicada, *Platypedia putnamii*, contained 0.1-12.6 µg/plug of psilocin so one would need to consume 3,000 to 300,000 wing-banger cicadas to have a mild psychedelic effect. *Massospora levispora* contains only 7.3-19.4 ng psilocybin/plug and so you would need to consume several million to feel any effect. Consequently, there is no reason to get excited about sampling cicadas for their mind-altering effects in humans.

Photos of periodic cicadas, including* Massospora*-infected cicada, courtesy of Tovi Lehmann. For more on this bizarre fungal pathogen and its periodic cicada host, see Tovi's article "Outracing all your devoted enemies? The periodic cicada (and its bizarre fungal pathogen)" in* FUNGI *2013, 6(3): 15-17.

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