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EDITORIAL

Fungus Farming Insects: Forgotten Pioneers of Agriculture

About 10,000-12,000 years ago our ancestors changed their nomadic hunter-gatherer life style and became ecological pioneers who cultivated food crops. Development of agriculture and a reliable food supply led to a change in society, with the establishment of permanent settlements, increases in population and the growth of cities and civilizations across the globe. The ecological success of humans has been largely due to the developments made in agriculture.

Humans were however only adapting knowledge already available to insects. Tiny insects have been farmers cultivating fungi as a food source for more than 40- 60 million years. Plant material which is the food source of insects is made up of complex organic molecules such as cellulose, hemicellullose and lignin. These are substances that cannot be digested by insects. Farming of fungi is a method used by insects to transform plant material into an easier to digest food source. Fungi, unlike insects, have the enzymes necessary to breakdown these complex molecules into simpler molecules.

Insect agriculture which is a complex system involving dispersal and seeding of spores, cultivation of the crop, use of antibiotics and sustainable harvesting is known in three groups of insects – the fungus growing ants, termites and beetles. These insect farmers were agricultural wizards and used sophisticated techniques that rival our own.

The agricultural strategies adopted by these insects are particularly interesting to us. Ants for example developed remarkable farming techniques. Fungal cultivation by attinine ants, which include the leafcutters, has been known for a long time and even mentioned in the creation myth of the Central American Mayan civilization (300-900 AD). The ants are involved in a symbiotic relationship with a fungus and an antibiotic producing *Streptomyces* bacterium. In this relationship, cut leaves produced by the ant is the manure on which minute species of fungi grow in isolation. These tiny ant farmers also search and collect bits of vegetation which are used to nourish their fungi that are grown in isolation on a large scale in underground gardens. The fungi cannot escape, so that wild and domestic fungi cannot get together and swap genes. The third partner in this symbiosis, the filamentous bacterium *Streptomyces* living on the bodies of the ants, produces antibiotics which suppress the growth of the specialized garden and virulent parasite *Escovopsis* (Ascomycotina). Through this mechanism, the ants have over the millennia, ensured that the fungal crop is pure bred and maintained sustainably protected from diseases and pests. Although two-thirds of the antibiotics discovered by humans are derived from *Streptomyces* bacteria, human discovery of antibiotics has a history of a mere seventy years.

An unusual example of fungal farming is found in the leaf rolling weevil *Euops chinensis* (Family Attelabidae) which has a symbiotic relationship with the fungus *Penicillium herquei*. The female attelabid weevil *E. chinensis* has developed specialized structures for leaf rolling and inoculating the fungus into the roll where the egg is laid. The symbiotic fungus *Penicillium herquei* produces an antibiotic (+)-scleroderolide which protects the fungal garden from other organisms.

Fungus–growing termites form one of the most complex colony and mound structures of any invertebrate group. Termite mounds are very tall and exist for a long time. Carbon dating has established that a set of four mounds found in the Congo's Miombo Woods are between 680 and 2200 years old. Associations in the fungus-growing termites are among the most sophisticated symbiotic interactions in the insect world. *Termitomyces* fungi are cultivated by termites and they sustain the growth of the insect colony by decomposing plant matter collected by the termites to make them digestible food.

Agricultural activities by fungus farming ants and termites therefore plays a prominent role in insect life. We have been studying an insect farmer, the ambrosia beetle which attacks stems of tea, *Camellia sinensis*, known as the Tea Shot-hole borer (TSHB) beetle (*Euwallaceae fornicatus* (Eichhoff) (Coleoptera: Scolytiae). The TSHB has a symbiotic fungus, the ambrosia fungus *Monacrosporium ambrosium* (syn *Fusarium ambrosium*, *Neocosmospora ambrosia*) which is the sole food source of both the larval stages and the adult TSHB. We have found that TSHB has the ability to produce pigmented naphthoquinones that can inhibit fungal growth. The naphthoquinones produced by the ambrosia fungus probably prevent the growth of other fungi in the TSHB galleries and maintains the purity of the ambrosia fungal garden in the galleries. TSHB therefore plays a role as a fungus farmer which cultivates and maintains the ambrosia fungus which is necessary to sustain the beetle gallery within TSHB galleries in tea stems.

Just as agricultural activities have helped to maintain and develop human societies for a relatively shorter period, they have contributed to the proliferation, resilience and sustainability of insects over a much longer period. We, as humans, have only been rediscovering the knowledge developed by insects. Insects however, made sure that

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their approach was sustainable so that they could exist for several millennia. Human strategies do not appear to put sustainability at the forefront and may ultimately contribute to the downfall of human civilization as we know it.

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