Ergothioneine from Fungi Connects Soil Health and Human Health

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In the sixteenth century Leonardo da Vinci reportedly stated that "we know more about the movement of celestial bodies than the soil underfoot." Actually, that may be even more true today. At least it seems like we spend more time and money looking into that "realm." Case in point, a new costly Webb Telescope was launched a million miles into space to probe the origin of the universe while we tend to neglect the soil underfoot that feeds us every day.

One thing we do know for sure is that most soil is teeming with microorganisms. It is thought that one teaspoon of soil contains more microbes than the number of people on earth. Among those are fungi that produce the potent antioxidant and anti-inflammatory amino acid, ergothioneine (ERGO), theorized by Bruce Ames (2018) to be a "longevity vitamin." According to his Triage Theory, a shortage of certain micronutrients like ERGO in the diet would result in damage to long-term health that is cumulative and leads to premature aging.

Humans cannot produce ERGO so they must obtain it from dietary sources, of which mushrooms are the leading dietary source. Ergothioneine thereby became a focus of our research at the Center for Plant and Mushroom Foods for Health at Penn State (Kalaras et al., 2017). Several reasons why ERGO consumption may be suboptimal began to emerge. In the USA mushroom consumption is relatively low compared to other countries worldwide. Coupled with this, other sources of ERGO in the food chain are low; many foods contain ERGO but at levels that are well below that of mushrooms and which consumption of a typical diet would yield very low levels of ERGO intake. Additionally, we hypothesized that soil-borne fungi presumably pass ERGO on to plants through their roots and that some modern agricultural practices might disrupt this process. This could lead to reduced ERGO levels in the food supply and thereby compromise our long-term health outcomes (Beelman et al., 2020). Supporting this hypothesis, we demonstrated that countries with lower estimated ERGO consumption were associated with higher incidence of some chronic neurological diseases of aging and lower life expectancies (Beelman et al., 2019).

Some conventional agricultural practices such as aggressive tillage (plowing) of soil are known to negatively impact fungal populations in the soil so we became interested to see if they reduce ERGO levels in crops. Fortunately, we were able to tap into a study ongoing since 1978 at Penn State that was employing three different levels of tillage from no-till to aggressive plowing. We found that ERGO concentrations declined as tillage intensity increased in corn, soybeans, and oats grown in three successive years by around 30% (Beelman et al., 2021), suggesting that tillage might be having a negative effect on soil fungi. Long-term soil tillage has previously been shown to negatively impact populations of arbuscular mycorrhizal fungi (AMF) (Bowles et al., 2017). Recently, studies were conducted by Carrara et al., (2023) to investigate this possible connection. Wheat, oats, asparagus, and black beans were grown in pots inoculated with single and mixed species of AMF. In all cases, AMF inoculations increased ERGO compared to uninoculated controls and a positive correlation between AMF colonization of the plant roots and ERGO content was observed.

Fortunately, there has been a growing interest in what is being called conservation or regenerative agriculture that focuses on farming practices that promote the health of our agricultural soils and maintain healthy populations of soil-borne fungi. Regenerative practices include reducing aggressive tillage, routine use of cover crops, and crop rotations as well as reduced usage of chemical fertilizers, pesticides, and herbicides commonly used in conventional agriculture. These regenerative practices are more "restorative" and less "extractive" than conventional practices that

degrade the soil over time. Aggressive tillage and some other conventional practices can sometimes result in permanent soil degradation of farm soils. In fact, a recent study (Thaler et al., 2021) estimated that 35% of the topsoil in the USA corn belt has already been significantly degraded. Also, Montgomery and Biklé (2016) have estimated that about a third of the world's agricultural land has already been degraded by loss of topsoil and history has documented that numerous previous societies have disappeared at least partly because they ruined their soil. Erosion of topsoil due to aggressive tillage can also lead to excessive runoff containing fertilizer and other farm chemicals that pollute streams and rivers causing significant environmental problems. Regenerative practices also help lower financial inputs and possibly lead to increased carbon sequestration that may help mitigate climate change. Hopefully, such changes can lead to healthier farm soils and more ERGO-rich foods that will improve our long-term health outcomes (Beelman et al., 2022) that provides a definite link between soil health and human health. Presumably, Leonardo would be well pleased.

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