

# Fungi from the Biblical Perspective: Design and Purpose in the Original Creation

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## Abstract

Fungi are intriguing organisms with a wealth of diversity in their morphology and ecology. Determining the fundamentals of their biology from a biblical perspective is a daunting but achievable task. This paper seeks to address the topic of fungal kinds by examining recent taxonomic data combined with new insights into the basic biology of the various types of fungi. Fungi can exist as single or multi-celled organisms, reproduce asexually and/or sexually, and can live in varying levels of intimacy with other species. To work toward a biblical creation model for mycology, this paper will address several questions. First, what was the originally intended role of fungi in creation, and when were they created? What can our current understanding of their symbiotic interactions with other organisms tell us about the original creation? How did pathogenicity arise as a trait of fungi? Answers to these and other questions will foster a more detailed and proper understanding of these important organisms and their relationship to creation as a whole.

**Keywords:** nutrient cycling, symbiosis, commensalism, pathogenesis

## Introduction

The theory of evolution is the prevailing paradigm in biology. According to this framework, all living things can trace their lineage back to a single common ancestor approximately 3 billion years ago, resulting in what Darwin called the “Tree of Life”. This has been the dominant paradigm in biology for the past 150 years, although there is a current debate on whether the Tree has a single root or exists as a web (Lawton 2009). In fact, current alternatives more closely resemble the Creation Orchard view (DeWitt 2007). To synthesize a comprehensive alternative to the materialistic Darwinian worldview regarding the history of life, all facets of biology must be considered. Toward this end, this manuscript will address the fungi, a fascinating group of organisms which have received scant attention in the biblical creation worldview to date.

Until relatively recently, fungi were considered to be part of the plant kingdom. This was mainly due to certain shared characteristics, such as apparent lack of motility, absorptive nutrition, and cosmopolitan distribution. It was not until the early 1700s that microscopic observations of fungi led to their classification as a separate taxonomic entity. Currently, it is estimated that approximately 1.5 million species of fungi exist, yet less than 10% of these have been described (Buckley 2008; Webster and Weber 2007). The unifying traits of the true fungi are: eukaryotic nuclei; non-photosynthetic, heterotrophic, absorptive nutrition; non-motile vegetative state; cell wall made

of chitin/chitosan; sexual reproduction by spores; and hyphal or yeast growth.

## Genesis of the Fungi

In the materialist narrative of the history of life, fungi arrived on the scene approximately 1 billion years ago, with the earliest fossilized fungi identified in Ordovician stratum dated approximately 460 million years ago (Redecker, Kodner, and Graham 2000). The current concept of fungal evolution places them as a relative of the animal kingdom, with the Choanoflagellates or the true slime molds being the last common ancestor between the animal and fungal taxa (Baldauf and Palmer 1993). Since that time, the true fungi have supposedly evolved into as few as four (Webster and Weber 2007) or as many as seven (Hibbett et al. 2007) different phyla. The best-described phyla are the Ascomycetes and Basidiomycetes, of which the best known members are the molds and mushrooms, respectively. These phyla demonstrate the complicated nature of fungal taxonomy, with unicellular yeasts and multicellular forms included as members of both phyla.

In the biblical creation worldview, fungi were created by God during the Creation Week approximately 6,000 years ago as a variety of different reproductively isolated kinds or baramin (*bara*=created, *min*=kind; Marsh 1941). The Bible does not describe precisely when these organisms were created, but we can logically deduce when they were likely created based on the reasoning that each

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created system at the end of each day was complete or “good” (Genesis 1; Gillen 2008)). In this way, we can deduce that the mycorrhizal, endophytic, and land-dwelling, saprophytic fungi were likely created on Day 3 along with plants, while other fungi (that is, animal-associated *Candida* spp. and the aquatic Chytridiomycetes) were created on Days 5 and 6. Alternatively, all of the fungi may have been created on Day 3 with the other “plants”, given the traditional Hebrew inclusion of fungi and bacteria in the plant kingdom (Gillen 2008; Kennard 2008). Irrespective of their day(s) of creation, discerning the individual baramin of fungi may be possible based on their mode(s) of reproduction and physical characteristics.

### Role of Fungi in Creation

Fungi have been isolated from every ecological niche on earth. They are able to survive temperatures ranging from about  $-12^{\circ}\text{C}$  to  $62^{\circ}\text{C}$  and are found in virtually all latitudes and altitudes. A major activity of fungi is decomposition of organic matter: up to half of the organic matter in tropical rainforests is degraded by fungi (Buckley 2008). This purpose of fungi cannot be overstated. These organisms are crucial for the breakdown of the stable biopolymer cellulose, which is the most abundant biopolymer on earth. Roughly 40% of plant cell wall material is comprised of cellulose (Deacon 2006), making the decomposition of cellulose crucial for nutrient cycling in nature.

The purpose of fungi in recycling organic material is consistent with an originally perfect creation. In the current debate between philosophical naturalism and biblical creationism, an important sticking point involves the relationship of life and death in the history of the universe. In the evolution paradigm, death is a necessary means of progress for advancement of organisms from simple to more complex. As part of the process of natural selection, it is a tool to allow for adaptation of organisms to various environmental niches. This stands in contrast to the role of death according to the Bible, where death is an enemy that will be destroyed when all of creation is restored to its original state after Christ’s return (1 Corinthians 15:26). This highlights the incongruity between the biblical creation and evolution worldviews: if spiritual and physical death are not a consequence of sin, then the Christian faith is vain because Christ had no reason to die and rise again. Therefore, the role of death in biology is crucial in this worldview debate.

Biologically speaking, there are differences between the modern and biblical concepts of death. The modern definition of death is the cessation of life, where life is “the property or quality that distinguishes living organisms from dead organisms and inanimate matter, manifested in functions

such as metabolism, growth, response to stimuli, and reproduction” (Morris 1982). However, this is not the definition of death used in the Hebrew Old Testament. In the original Hebrew, death (*mût*) exists in relationship to those organisms with a living soul (*nephesh chayyah*): humans and vertebrate animals (Todhunter 2006). Before the Fall of Adam into sin, living souls did not cease to exist (hence, death did not exist; 1 Corinthians 15:21, 22). Since plants were not created with a living soul and were given for food (Genesis 1:29–30), it is logical that a mechanism to process the inedible plant material and animal waste would exist to allow for efficient recycling of their nutrients.

In addition to their role in nutrient cycling, fungi also participate in important commensal relationships. Scientists estimate that >75% of vascular plants have symbiotic relationships with fungi in the form of mycorrhizal interactions (Prescott, Harley, and Klein 1993). If endophytic and other commensal interactions are included, fungi engage in intimate associations with approximately 60% of all plant species (Buckley 2008). Fungi are also involved in symbioses with animals, although these types of relationships are not as widespread (Aanen and Boomsma 2006; Akin and Borneman 1990; Deacon 2006; Wubah, Akin, and Borneman 1993). These types of interactions tell us something more about the original purpose of fungi in creation. Indeed, because the original creation was “very good”, we might expect intimate associations of fungi with other organisms in which both benefit.

### Fungal Associations with Plants

#### *Mycorrhizae*

Many beneficial interactions exist between plants and fungi. Much research has been done to explore these relationships, and they can be characterized as either mycorrhizal, endophytic, or lichen. Mycorrhizae (“fungus root”) are a type of symbiotic relationship whereby plants provide the fungus with carbon, and the fungus extends the reach of the plant in the soil for needed water and nutrients (Buckley 2008). Recent research has demonstrated that mycorrhizal fungi also confer enhanced resistance to numerous soilborne plant pathogens, including other fungi and nematodes (Agrios 2005).

Mycorrhizal interactions are classified by the location of the fungus in the plant, and are either ectomycorrhizal (intercellular), or endomycorrhizal (intracellular). Ectomycorrhizae are usually produced by interaction of forest tree roots with either basidiomycete (that is, mushrooms, puffballs) or ascomycete (that is, mold) fungi (Deacon 2006). Primarily, ectomycorrhizae are located on the feeder roots of woody plants. These roots are devoid of root hairs, making the presence of the fungus crucial

for increasing the functional surface area of the plant root. Nutrient uptake is further enhanced by expansion of the mycorrhizae into the surrounding soil and subsequent transport of water, nitrogen, and minerals through the fungus to the plant root (Deacon 2006).

Ectomycorrhizal fungi typically form mycelial cords to aid in soil penetration, and form a network of hyphae in the soil. Individual plants are linked to each other by this network of hyphae allowing nutrients to move between plants (Deacon 2006). Additionally, the presence of this hyphal web facilitates the turnover of nutrients from plant rootlets, up to 90% of which are replaced each year (Deacon 2006). Without this reclamation system in place, the nutrients stored in these rootlets would likely be lost, leading to a steady decline in available carbon and nitrogen for plant growth.

Endomycorrhizae are the more well-known and studied type of mycorrhizal interaction and are more cosmopolitan in distribution than the ectomycorrhizae (Deacon 2006). In contrast to the ectomycorrhizae, endomycorrhizae are primarily formed by zygomycete fungi. Endomycorrhizae are also known as arbuscular mycorrhizal (AM) fungi due to the formation of specialized feeding structures called arbuscles in the interstitial space between the cell membrane and cell wall of root cortical cells (Deacon 2006; Hennigan 2009). Arbuscles allow for efficient nutrient exchange between the fungus and the plant, as the cells harboring the arbuscles are not killed by the presence of the fungus. Current secular understanding of the development of fungi is based on fossilized AM fungi found in Ordovician and Devonian strata and dated to ~460–354 million years ago. Interestingly, these ancient AM appear virtually identical to contemporary AM and have not changed in the intervening proposed evolutionary timeframe (Remy et al. 1994), casting doubt on their development via materialistic processes over millions of years.

The role of AM fungi within a creation framework has been recently explored (Hennigan 2009). Much like the ectomycorrhizae, AM fungi form networks of hyphae in the soil and facilitate the exchange of nutrients between individual plants (Smith, Read, and Harley 1997). These networks assist in establishing plants in soil, and may have enhanced plant re-colonization of land after the Flood recorded in Genesis 7 and 8. AM fungi in particular may have played a bigger role than the ectomycorrhizae in this due to their expanded host range. Regardless, mycorrhizae may constitute an originally created mutualism that allows plants to grow optimally in all types of soils (Agrios 2005).

Conversely, mycorrhizae may have been originally

created to restrict plants to particular ecological niches. Using various dune-inhabiting species of plants, Francis and Read demonstrated the differential response of these plants to AM fungi, with *Plantago lanceolata* showing enhanced growth with the mycorrhizae and other species showing repressed growth (Francis and Read 1995). This research built on the work of Grubb, who found that in the chalk grassland ecosystem in Great Britain four different groups of annuals and biennials existed with little mixing of the populations from groups B, C, and D (plants restricted to open habitats enduring regular disturbance) with the population of group A (plants in a closed turf habitat) (Grubb 1976). Francis and Read (1995) suggest that the reason certain species are unable to colonize exposed soil in these closed ecosystems is due to the presence of AM fungi. It is also interesting that many agriculturally important weed species are not mycorrhizal, and are inhibited by the presence of mycorrhizae when trying to invade so-called “closed” plant communities (Francis and Read 1994). It is possible that the loss of mycorrhizal associations by these plants is part of the original Curse (Genesis 3:17–18), and may be part of the reason these weed species devolved from their original created state.

### Endophytes

Commensal fungal interactions with plants are not restricted to the roots. Within the last hundred years, endophytic fungi have been described that reside in plant tissues yet do not cause disease (Carroll 1988). Similar to the ectomycorrhizae, endophytic fungi are primarily ascomycetes, with a few basidiomycete endophytic fungi identified (Rodriguez and Redman 2008). In contrast to the mycorrhizae, endophytes seem to be important in stress tolerance and enhancing plant biomass (Rodriguez and Redman 2008) and may therefore work in concert with mycorrhizae for optimal plant growth.

Recent work has revealed the importance of endophytic fungi in salt- and heat-stress tolerance (Rodriguez et al. 2008). In their study, Rodriguez and colleagues showed that endophytes isolated from dunegrass were able to colonize both panic grass (representative monocot) and tomato (representative eudicot). Interestingly, endophytes appear to be fine-tuned for particular stresses, as those isolated from grasses in different ecological niches only conferred resistance to the stresses particular to that niche: salt-stress tolerance for coastal grasses, heat-stress tolerance for geothermal soil grasses, and disease and drought tolerance for agricultural grasses (Rodriguez et al. 2008).

The complexity of these interactions is greater than was initially anticipated; a three-way symbiosis

necessary for thermal tolerance in geothermal soils has been recently described (Marquez et al. 2007). In this interaction, the researchers demonstrated that heat-tolerance induced by the endophyte in panic grass was dependent on the presence of a fungal virus. Plants with virus-free endophytes were susceptible to killing by 65°C, whereas plants with virus-infected endophytes could survive at that temperature. Heat tolerance was conferred on tomatoes upon infection with the virus-containing endophyte, demonstrating the broadness of these higher-order interactions and suggesting that this kind of interaction was likely present during Creation Week. Indeed, these symbioses appear to have been designed to enable re-colonization of the varied soil types found in the post-Flood world.

### Lichens

Fungal symbiotic/commensal relationships are not restricted to multicellular plants. A famous example of this is the lichens. Lichens are symbiotic partnerships between fungi and photosynthetic microbes, such as algae or cyanobacteria (Deacon 2006). In this relationship, the fungus (mycobiont) provides a physical structure in which the photosynthetic partner (photobiont) resides, and the photobiont provides the mycobiont with energy via carbon fixation (Deacon 2006; Webster and Weber 2007).

There are an estimated 18,000 species of lichens and ~98% of these associations involve ascomycete fungi; the remaining lichens involve basidiomycetes (Webster and Weber 2007). As seen above with other symbiotic associations, lichens show an increased resistance to desiccation and other stresses and therefore are found in regions inhospitable to vascular plants (Webster and Weber 2007). These peculiar organisms are present in all ecological zones and can even colonize bare rock. Some lichens exhibit an extremely slow growth rate and certain individual lichen colonies have been estimated to be over 1,000 years old (Karlen and Black 2002).

Lichens demonstrate the potential for plasticity of higher-order interactions between phyla. Often, geographically limited communities of lichens having disparate mycobiont members share a single or few photobiont partners (Webster and Weber 2007). In fact, some lichen species have been shown to “steal” photobiont partners from other lichens (Honegger 1993). Different photobiont species will generally provide the mycobiont with different carbohydrates: cyanobacteria provide glucose, whereas green algae provide polyols, which are alcohols of various sizes with multiple hydroxyl groups. (Webster and Weber 2007).

Lichens pose a dilemma for Darwinian evolution. The advantage of the symbiosis to the mycobiont

is obvious (steady carbohydrate source), but the advantage to the photobiont partner is unclear. The most likely evolutionary advantage for the photobiont might be that the mycobiont provides a protective cover for development of the photosynthetic partner, which supports the hypothesis that lichens preceded vascular plants in the colonization of land (Webster and Weber 2007). Further supporting this scenario are molecular clock data indicating that lichen symbioses arose before vascular plants approximately 1 billion years ago, according to the Darwinian paradigm (Heckman et al. 2001). However, the traditional evolutionary view of land colonization by plants is supported by fossil evidence showing that spore-producing plants (that is, bryophytes—liverworts, mosses, etc.) first colonized land approximately 475 million years ago during the Ordovician age according to the evolutionary geologic timescale (Campbell 1990; Wellman, Osterloff, and Mohiuddin 2003). Interestingly, the appearance of plant spores in Ordovician strata parallels the appearance of fungi in the same strata (Redecker, Kodner, and Graham 2000; Wellman, Osterloff, and Mohiuddin 2003). Both of these hypotheses are colored by evolutionary presuppositions. In the biblical creation paradigm, all of these organisms were present from the beginning. The biblical creation view of the geologic column construes these layers as representative of different ecological zones and their order of burial during the Flood and its aftermath (Woodmorappe 2000). Therefore, geologic evidence supports the hypothesis that fungi and plants inhabited the same ecological zones, and that the land was colonized by both lichens and vascular plants from the beginning.

Furthermore, lichens pose a serious challenge for evolution due to the intricate nature of the interaction between the mycobiont and photobiont partners. The interaction of both partners is recalcitrant to selection, as the putative ancestors of both mycobiont and photobiont species would have been free-living. Any selective pressure to move from the relatively gentle conditions of ocean habitats to the harsh conditions of rock faces via symbiosis would have had to work against the already stable free-living lifestyle employed by the individual partner species. Coupled with fossil evidence from the Devonian strata demonstrating a lichen symbiosis virtually indistinguishable from extant lichens (Taylor et al. 1995), the probability of this symbiosis developing by chance is highly unlikely. Therefore, lichen symbioses attest to being designed, and explicitly demonstrate creation’s obedience to God’s command to “fill the earth” (Genesis 9:1).

### Fungal Associations with Animals

In contrast to the Plant Kingdom, fewer commensal

associations have been described between fungi and animals. For example, certain species of termites, ants, wasps, and beetles are the only known insect species in symbiotic interactions with fungi (Deacon 2006). In the ant, beetle, and termite symbioses, the insects grow the fungi for food (Aanen and Boomsma 2006; Deacon 2006). Wood wasps use fungi for a slightly different purpose: to “pre-digest” wood in dead or dying trees for consumption by the wasp larvae (Deacon 2006).

From the evolutionary perspective, these insects utilize fungi in order to make use of available cellulose found in plants (Deacon 2006). These symbioses are believed to be highly evolved, as the fungus-insect interactions are mostly specific between insect and fungal taxa (Mueller and Gerardo 2002; Mueller and Rabeling 2008). Recent work focusing on the timeline of ant-fungus mutualism proposes that the oldest type of interaction involves fungi that are capable of saprophytic growth (that is, free of the ant symbiont), with interactions involving obligate mutualism such as the leaf-cutter ant symbiosis being a recent development (Schultz and Brady 2008).

The biblical worldview differs from the evolutionary worldview mainly in regard to the origins and timescale of the development of these symbiotic interactions. Using phylogeny data for the insect species which make use of these interactions, it may be reasonably inferred that current “agricultural” insects (that is, attine ants) descended from individual baramin, one baramin for each agricultural ant and termite family (Mueller and Gerardo 2002). Presumably, these insects were originally designed to use leaf litter as compost for growing fungi, with recent corruption of this purpose resulting in the destruction of living plant tissue (Mueller and Rabeling 2008). The beetle-fungus and wood wasp mutualisms seem to have been created for a different purpose. These mutualisms take advantage of dead or damaged trees and may have been originally created to exploit nutrient recycling in completing their life cycles. These symbioses have also been corrupted since the Fall, resulting in damage to living trees and causing significant economic loss (Anonymous 2006, 2009).

Higher animals (that is, Bilateria—the group of eumetazoan animals having bilateral symmetry) have also been shown to share commensal relationships with fungi, although there are relatively few examples. Various “primitive” fungi are known to inhabit the gastrointestinal tract of various herbivores and aid in digestion of plant matter (Akin and Borneman 1990; Wubah, Akin, and Borneman 1993). These fungi, particularly of the Phylum Chytridiomycota, secrete enzymes for the degradation of recalcitrant plant polymers such as xylan, hemicellulose, and cellulose (Wubah, Akin, and Borneman 1993). Given that all

animals were herbivorous in the original creation (Genesis 1:29–30), we can infer that these kinds of commensal fungi were likely present in the GI tracts of most, if not all, animals. The change in diet after the Flood (Genesis 9:2–4) likely resulted in an alteration in the microflora of certain animal species so that they could not digest vegetation efficiently, and therefore became carnivorous.

### Effects of the Curse

As a result of man’s rebellion, God allowed man to see what the world is like without His sustaining power maintaining all the interconnected relationships He had created. This allowed these relationships to degenerate to varying degrees, as typified by the rise of pathogenic relationships between various microbes and the vascular plants, animals, and humans. It is interesting that of the estimated 1.5 million fungi, only slightly more than 10,000 (<1%) cause diseases of plants and animals (Agrios 2005; Deacon 2006). This stands in stark contrast to the materialistic view that pathogenic fungi have evolved to parasitize plants and animals over the last ~400 million years. Since Darwinian evolution supposes random mutations with subsequent selection, it seems reasonable to expect that significantly more than 1% of fungi would parasitize other organisms. This discrepancy could be attributed to the defense mechanisms of higher organisms, although that reasoning would presuppose the evolution of defense mechanisms against threats which had yet to exist. It is far more likely that plant and animal defense mechanisms were originally designed to allow efficient interaction between host and microbe in a mutualistic interaction and only became “defensive” in nature once these interactions degenerated.

### Plant Pathogens

While many commensal and symbiotic relationships exist between fungi and plants, there are a number of detrimental associations involving fungal parasites and pathogens. In the evolutionary worldview, plant disease-causing fungi evolved pathogenicity as a lifestyle over the last few million years during their coexistence with plants. The current view is one of an arms race: pathogens evolve mechanisms to use plants for nutrition and reproduction, and plants likewise evolve mechanisms to resist/evade them. This is in stark contrast to the biblical creation worldview, where plant diseases are the result of the Curse by God on the whole of creation due to man’s sin (Genesis 3:17–18). In this worldview, pathogenicity is the result of the corruption of the originally designed commensal and symbiotic interactions between plants and microorganisms (such as fungi). A proper understanding of how pathogenicity arose will enable

us to develop better strategies for intervention.

The current data supporting Flor's gene-for-gene hypothesis as well as our current understanding of the establishment of basic compatibility between host and pathogen are consistent with a Modification/Displacement Model of disease origins (Flor 1946; Purdom and Francis 2008). Under this model, microbes were initially created with particular function(s) necessary for maintenance of life on earth. Their presence was restricted to particular niches where they functioned according to the original created design. Following the Fall, the Curse brought about modification of certain biochemical compounds and cellular structures which have since become the focus of disease research (that is, toxins, invasion structures, etc.). The first mention of disease in the Bible does not occur until after the Flood account, during Job's tempting by Satan (Job 2:6–8). Perhaps the Flood caused massive displacement of microbes from their initial habitats through the complete destruction and remodeling of the earth's surface, which lead to the introduction of these microbes into new ecological niches including plants, animals, and man.

There are basically two types of plant pathogens (Agrios 2005): obligate pathogens (that is, biotrophs) and facultative pathogens (that is, hemibiotrophs and necrotrophs). Biotrophic fungi require living plant tissue as a substrate, where they complete their entire life cycle. In contrast, hemibiotrophic and necrotrophic fungi complete at least part of their life cycles on dead plant tissue. A cursory comparison of plant pathogenic fungi and plant symbiotic fungi reveals that in many cases both pathogen and non-pathogen utilize similar (if not identical) structures for associating with their plant host. For example, both AM fungi and powdery mildews utilize haustoria for nutrient acquisition from plants. The major difference between these two interactions is that the AM fungi reciprocate nutrient exchange with their host, whereas the powdery mildew exploits its host for nutrition.

A more pointed example of the degeneration of these interactions comes from the endophytic fungi. Carroll defended the evolution of endophytic fungi from plant pathogens on three points: 1) endophytes can cause pathogenic symptoms during plant stress; 2) some crop pathogens live commensally with weeds growing among the crop host; 3) some pathogens are sister species of endophytic fungi on the same or related hosts (Carroll 1988). However, this hypothesis on the development of endophytic relationships presupposes Darwinian evolution to be true. These data also support the biblically-based hypothesis that endophytes were originally created to live symbiotically with plants, and that certain pathogenic relationships developed via the degeneration of these highly

coordinated interactions. Lack of proper controlled growth in the host can lead to the development of pathogenicity from a commensal or mutualistic state. A single-gene mutation in the grass endophyte *Epichloë festucae* changes the interaction of this fungus and its host from a mutualistic to parasitic interaction, and results in among other things uncontrolled growth of the fungus (Tanaka et al. 2006). Likewise, inbred crop species certainly lack key signaling and recognition-related genes present in their wild "weed" relatives and important for resistance to pathogens (Agrios 2005), which explains the presence of pathogens as endophytes in these related species. Therefore, the biblical creation model is robust and can account for the development of plant pathogens from saprophytic or mutualistic fungal species.

### Animal Pathogens

Of the fungi which cause diseases of higher eukaryotes, only about 200 have been shown to cause disease in animals. This is likely reflective of the overall lower number of mutualistic interactions in which these organisms participate. Many of the mycoses studied to date involve humans as a terminal host, with underlying immune impairment being chiefly responsible for host susceptibility (McNeil et al. 2001). Many of the important disease-causing fungal genera (including *Aspergillus*, *Penicillium*, *Blastomyces*, *Histoplasma*, *Coccidioides*, and *Cryptococcus*) presumably persist in the environment as saprophytic fungi (Heitman 2006). There are three interesting exceptions: *Candida albicans*, *Pneumocystis* spp., and the dermatophytic fungi. These three groups of fungi are host acquired, and in the case of *Pneumocystis* acquisition of infection only occurs from another infected host. *Candida* and *Pneumocystis* pathogenic relationships are described in more detail below.

*C. albicans* is a commensal yeast of humans and warm-blooded animals which normally resides on skin and mucosal surfaces (Deacon 2006). This commensal yeast serves as a model human fungal pathogen for the study of phenotypic switching, whereby a fungus grows as one morphotype (that is, yeast or hyphae) in the commensal state and switches to the other morphotype in the pathogenic state. In the case of *C. albicans*, the commensal form is primarily yeast and the hyphal form is important for tissue invasion. Certain host factors, such as body temperature, regulate this change in morphology (Webster and Weber 2007).

Recently, genome sequences of eight different *Candida* species were compared to attempt to describe the development of pathogenicity and sexual reproduction in these fungi (Butler et al. 2009). The authors found that expansion of certain gene families,

presumably by gene duplication, was present in the pathogenic species of *Candida*. These proteins are important in adhesion to epithelial cells and therefore pathogenicity, but also play an important role in biofilm formation (Bennett 2009). Similar observations were made for other cell-wall protein families in *Candida* (Butler et al. 2009). Bennett proposed that these gene families, which display high mutation rates, “provide ... a selective advantage for invasion and infection of the mammalian host.” (Bennett 2009). This statement suggests a Darwinian view that pathogenic relationships are a kind of “advancement” in the development of a species. Alternatively, these data confirm the biblical creation view that pathogenic interactions portray a degeneration of the originally created commensal/mutualistic interactions via modification of the ancestral kinds (that is, baramin). These modifications resulting in pathogenesis include mechanisms such as gene family expansion, point mutations, and genome rearrangements (Butler et al. 2009; Morschhäuser et al. 2000). Interestingly, a biblical creation model describing a mechanism for rapid diversification within created kinds via Altruistic Genetic Elements (AGE) has been proposed that involves genomic rearrangements, DNA transposition, and horizontal gene transfer (Wood 2003).

*Pneumocystis* is a fascinating genus of fungi which are quite different from the other animal pathogenic fungi mentioned so far. Species of *Pneumocystis* have been found in the lungs of a wide assortment of mammals (Deacon 2006), yet there exists a pronounced host specificity for each *Pneumocystis* species (Wakefield 2002). As a group, *Pneumocystis* is obligately commensal and recalcitrant to growth under laboratory conditions (Heitman 2006). These properties make research on the ecology and host-pathogen interaction difficult. Unlike the other fungal pathogens of humans, *Pneumocystis* appears to be transmissible between hosts (Heitman 2006) and uses cholesterol instead of ergosterol as its main membrane sterol (Webster and Weber 2007).

The unique properties of *Pneumocystis* make a materialistic explanation of their origin difficult. They are believed to be relatively ancient fungi, taxonomically near the branch point between Ascomycetes and Basidiomycetes (James et al. 2006). Over time, they have formed a strong commensal relationship with their host, to the point that individual species of *Pneumocystis* are host restricted and only associate with a particular species of host. Generally speaking, the Darwinian view of commensal evolution consists of co-evolution of two (or more) species over many generations with adaptation of the symbiont from parasite to commensal to mutualist (Ewald 1987). Under this paradigm, *Pneumocystis*

presumably began its interaction with mammals as a parasite acquired from the environment and has gradually evolved to become an apparent commensal, only causing disease as a result of immune deficiency (Heitman 2006).

However, this materialistic explanation does not provide a satisfying account for their origins, especially in light of their obligate lifestyle. For example, *Pneumocystis* has never been isolated from the environment, and no extant examples of closely related fungi exist; *Pneumocystis* is classified as an Ascomycete, but all members of this genera belong to a unique taxonomic Class, Order, and Family (Heitman 2006; Thomas and Limper 2007; Webster and Weber 2007). Furthermore, individual *Pneumocystis* species have been shown to display significant host restriction, such that each *Pneumocystis* species is associated with a specific mammalian host (Gigliotti et al. 1993). From a Darwinian perspective, this implies that the *Pneumocystis*-mammal interaction formed immediately after the supposed split of the mammalian lineage from the Tree of Life. This seems highly unlikely given the lack of environmental isolates nor any closely related species as symbionts of other animal taxa. Indeed, the biggest impediment to establishment of a symbiotic relationship is overcoming host immunity, which would likely require numerous attempts (Doebeli and Knowlton 1998).

From a biblical creation perspective, it may be that *Pneumocystis* spp. were originally designed to exist with mammals much like endophytic and mycorrhizal fungi exist with plants. Interestingly, it has been recently observed that colonization by *Pneumocystis* may be protective against infection by viruses (Cavallini Sanches et al. 2006), which is a general phenomenon that has been described in other contexts, including plant-associated fungi (Agrios 2005; Barton et al. 2007; Oliver et al. 2009; Rodriguez et al. 2008). This would explain the innocuous nature of *Pneumocystis* in immunocompetent hosts, as it seems likely that their original purpose would be to prime the immune system in the respiratory tract and/or occupy niches in the respiratory epithelium to impede invasion by other microbes. More research needs to be done to explore their possible role in healthy hosts in light of the biblical creation paradigm so that disease caused by these microbes can be properly understood.

## Conclusion

Fungi are intriguing organisms, with similarities to both plants and animals. They play a vital role in earth's ecosystem and are responsible for much of the turnover of organic compounds in the biosphere. In addition, fungi work synergistically with plants to increase plant biomass and assist in plant colonization

of inhospitable substrates. These interactions are testaments to design. The relatively small number of pathogenic interactions compared to the total number of fungi allude to the original created order. Experimental evidence showing the effects of gene mutation in numerous systems demonstrate the ease by which these complex interactions can be corrupted. Future research in plant pathology and medical mycology may further illuminate the impact of the Curse on fungal mutualistic processes, and may help us better understand how different the current world is from the original, perfect creation.

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