MYCOLOGY ANSWERS

HOW DO FUNGI DEGRADE AND OBTAIN NUTRIENTS FROM CELLULOSE?

A great deal of research activity has been directed towards increasing our understanding of the mechanism(s) by which fungi affect cellulose in the natural environment. In very general terms, cellulose degradation occurs as the result of the production of appropriate extracellular enzymes (cellulases) and a large number of fungal species do produce such enzymes. However, information relating to the activity of fungal cellulases has been pieced together from many experiments using purified enzymes and culture filtrates from fungi normally exhibiting degradative activity. It is quite clear that the degradative process is complex and occurs as the result of several biochemical steps. The impetus for such research has arisen partly from an academic viewpoint but also in relation to the commercial exploitation of fungal cellulases. In addition, it provides greater understanding of the means by which decomposition of plant materials occurs and also of the mechanisms by which pathogenic fungi gain entry into and exploit healthy plants.

Fungi require sources of organic carbon for growth and development. Most organic carbon in the environment occurs as carbohydrates bound into the major components of plant tissues. However, plant materials are highly variable in composition and those carbohydrates are bound in different forms and in different relative amounts. Much plant carbohydrate is present in complex forms. In general terms, plant tissues are made up from celluloses (polymer of D-glucose), hemicelluloses (xylans and mannans), lignins (polymers of phenylpropane), other polysaccharides and glycoproteins. These polymers are laid down in close associations and the specific mix of neighbouring components may influence the accessibility of cellulose for microbial enzyme degradation. Plant cell walls are multilayered, each linked together but with slightly different constituent components. However, a large number of fungi are efficient cellulose degraders (e.g. *Trichoderma reesei, T. viride*) and, providing that sufficient water is available, the penetrative nature of hyphal growth ensures that extracellular enzymes quickly reach into plant tissues.

Cellulose is a major component of plant materials and is composed of microfibrils (chains of molecules complexed together). It is a polymer of D-linked glucose and is hydrolysed by the action of cellulases. In this process, cellulose fibrils are degraded by a series of enzyme reactions. In the first step the enzyme endo β(1-4)-glucanase splits the cross links (glucosyl bonds) between the component glucan chains which results in the formation of unbroken, single β(1-4)-glucan chains. A second enzyme β(1-4)-D-glucan cellobiohydrolase degrades those β(1-4)-glucan chains (cellulose chains) to give cellobiose (a disaccharide). Subsequently, the cellobiose is converted to glucose by the activity of another enzyme β(1-4)-glucosidase. In this way glucose is liberated from cellulose microfibrils and can be absorbed into fungal hyphae. It is clear that the first enzyme (endo β(1-4)-D-glucanase) creates sites at which the second enzyme (β(1-4)-D-glucan cellobiohydrolase) can act. The full enzyme complex is required for efficient degradation and nutrient release since the enzymes act synergistically i.e. their action in combination is greater than the sum of the individual activities.

It is possible that some fungi produce several forms of these enzymes and this apparent multiplicity of form has complicated the elucidation of the degradation system. However, it is likely that at least some confusion may have arisen from the presence of artifacts of purification and very low levels of impurities in assay systems. Further investigations at molecular level are likely to improve our understanding in this area. Cellulase enzymes are produced by fungi in response to the presence of cellobiose (disaccharide) which initially acts as an inducer, although higher levels of cellobiose cause repression of cellulase enzyme activity. It is also important to note that in addition to the complex of cellulase enzymes mentioned here other oxidative enzymes may also have a role to play in cellulose degradation e.g. cellobiose oxidase.

Some plant materials are woody and thickened, containing large amounts of lignin laid down in cell walls. This provides mechanical strength and resistance to plant tissues since the lignin component is not easily degraded by microbial enzymes (much plant cellulose is encrusted with lignin and is therefore unavailable to many fungal species). These thickened tissues are recalcitrant to degradation and are much less easily broken down by fungi. Relatively few fungi are capable of lignin degradation but some species are efficient degraders (e.g. white rot fungi such as *Phanerochaete chrysosporium*, *Rigidoporus ulmarius*, *Trametes* spp) and these species can delignify plant cellulose. Fungi that cause wood rot without destroying lignin are known as brown rots e.g. *Serpula lacrymans*. In the natural environment plant materials are usually colonised by a number of different fungal species and also by bacteria, and the suite of microbial enzymes that are released by that population often results in efficient decomposition of the plant debris.

It is clear that cellulases are also important enzymes for plant pathogens, aiding entry into and ramification through living plant tissues, providing the proliferating mycelium with nutrients. However, some virulent pathogens efficiently enter plant tissues without causing a great deal of disruption to the structural integrity and although these enzymes have a role to play they are by no means the only determining factor in pathogenicity.

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