MYCOLOGY ANSWERS

OLD PAPERS, MANUSCRIPTS AND BOOKS OFTEN DEVELOP BROWN SPOTS AND PATCHES; ARE THESE CAUSED BY FUNGI?

The ancient Chinese were the first to make paper, in the second century AD, using silk and vegetable fibres. The raw materials were teased out and loosened under water to make a slurry. With gentle agitation the fibres were formed into a thin layer which was then filtered out on to a porous support such as a fine meshed cloth, to make a sheet. In Europe 2,000 years later, cotton and linen rags were often used as the starting material.

Today the manufacture of paper is a sophisticated industry with a worldwide annual production of over 120 million metric tons. Most modern paper is produced by the chemical pulping of wood chips using a solution of sodium sulphide and sodium hydroxide (the kraft process). During this treatment most of the lignin, resins and natural carbohydrates dissolve and are disposed of. The remaining fibres are strong and can be used directly for brown paper and packaging or may be bleached by chlorination and then brightened with chlorine dioxide for white paper production.

Fungi are important spoilage agents and paper can be subject to attack if sufficient water is available to support growth. Degradation of cellulose and lignin can begin in wood chips even before pulping and paper processing. In fact some species (e.g. *Phanerochaete chrysosporium*) are so efficient in wood and paper degradation that much research effort is now directed into developing the use of fungi and/or fungal enzymes for biopulping, as a less environmentally damaging replacement for steps in the more traditional mechanical and chemical treatments in paper production.

Acidity is always a problem for the long term preservation of paper, adding to the speed of discolouration. The degree of acidity is heavily influenced by the production process. The long term survival of resin sized paper is often poor since it contains alum which is acid. Any residual bleaching agents left in the paper also result in its deterioration and discolouration. Contaminating fungal species are almost invariably acidophiles and are therefore able to exploit such an acid environment. In addition inks used for writing and printing are often acid and their presence may lead to eventual puncturing of the paper. Exposure to light also damages paper, making it brittle, even after a very short period of time. As well as this paper absorbs and tends to hold on to a great deal of moisture from the environment. Excessive moisture will weaken paper and also readily promotes the growth of microbes.

Paper is mainly composed from cellulose fibres with varying amounts of gelatin size and old books also contain quantities of bookbinders paste (flour and dextrin), all of which are good sources of nutrients and can act as useful substrates for the growth of many fungi. Some fungi will live preferentially on the size and some on the cellulose fibres. The most common fungi to be found on old papers are species of *Chaetomium* and *Penicillium* as well as *Trichoderma viride, Cladosporium herbarum* and *Stachybotrys alba.* In damp conditions, particularly in bathrooms and kitchens where humidity is high and condensation provides a supply of moisture, *Chaetomium globosum* may grow on wallpaper, utilizing the cellulose fibres. At a relative humidity of 70% or over fungi are prone to spread very fast over the surface of books and through the structure of the bindings, particularly if they are left undisturbed. Many species, particularly *Trichoderma* and *Penicillium*, readily form huge numbers of spores which are easily dispersed and will act as sources of new infection. Paper quickly yellows under such attack and some fungi (such as *Aspergillus* species) liberate acids from their growing mycelium, in addition to cellulolytic enzymes, eventually perforating the paper. Brown, pink or yellow spots form rapidly, probably due to the production of pigmented products (secondary metabolites), which may obliterate drawings and writing. In a short time the paper surface may be

eroded and the brittleness of the paper will increase. In addition, iron salts accumulate in damaged areas and form dark marks. Iron is a frequent impurity in paper causing rusty brown spots known as foxing. Foxing may be produced by a number of factors but it is usually attributable, in the major part, to microbial action.

In humid conditions fungal growth may be very extensive and penetrating. However, superficial mould growth can often be lightly brushed off (but be careful not to inhale airborne spores) and, providing that dampness can be effectively removed, will probably cause no further problem. It may be possible to gently, bleach out water based stains and fox marks, but treatment should be carried out with great caution and care in order to preserve any valuable written or printed marks. Such treatment may liberate water based paints from the surface of the paper, so professional advise should be sought. All important papers should always be stored under dry, well aerated conditions, away from bright light, and should be inspected periodically for problems.

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