3- Fungal Growth and Reproduction

3.1 Physical Requirements for Growth

- Temperature: into four broad categories in terms of their temperature ranges for growth: psychrophiles (cold-loving), mesophiles (which grow at moderate temperatures), thermophiles (heat-loving).
  - **Psychrophilic fungi** are defined as having optimum growth at no more than 16°C and maximum growth of about 20°C. In many cases they would be expected to grow down to 4°C or lower, whilst psychrotrophic fungi (psychrotolrant) would be those that can grow at low temperatures but have optimal and maximal above 20°C. There are many environments that could suit these organisms, including the polar and alpine regions.
  - Most fungi are **mesophilic**: commonly growing within the range 10–40°C, though with different tolerances within this range. For routine purposes these fungi can usually be grown at room temperature (22–25°C). Two important examples shown in Fig. 1 are *Aspergillus flavus*, which produces the potent aflatoxins in stored grain products, and *Penicillium chrysogenum*, used for the commercial production of penicillins.
  - **Thermophilic fungi** are defined as having a minimum growth temperature of 20°C or above, a maximum growth temperature of 50°C or above, and an optimum in the range of about 40–50°C.

- High temperature stress (or heat shock) on fungal cells, thermal damage can disrupt hydrogen bonding and hydrophobic interactions, leading to general denaturation of proteins and nucleic acids. **Heat-shock responses** in fungi occur when cells are rapidly shifted to elevated temperatures, and if this is sublethal, induced synthesis of a specific set of proteins – the highly conserved "heat-shock proteins" (HSPs) – occurs. HSPs play numerous physiological roles, including thermoprotection.
- **Hydrogen ion concentration (pH) and fungal growth**: The responses of fungi to culture pH need to be assessed in strongly buffered media, because otherwise fungi can rapidly change the pH by selective uptake or exchange of ions. Mixtures of KH_2PO_4 and K2HPO4 are commonly used for this purpose. It is then found that many fungi will grow over the pH range 4.0–8.5, or sometimes 3.0–9.0, and they show relatively broad pH optima of about 5.0–7.0. However individual species vary within this "normal" range, as shown by the three representative examples in Fig. 1. Several fungi are acid-tolerant, including some yeasts which grow in the stomachs of animals and some mycelial fungi (*Aspergillus*, *Penicillium*, and *Fusarium* spp.) which will grow at pH 2.0. But their pH optimum in culture is usually 5.5–6.0. Truly acidophilic fungi, able to grow down to pH 1 or 2, are found in a few environments such as coal refuse tips and acidic mine wastes; many of these species are yeasts.
- Fungal cultivation media acidified with organic acids (e.g. acetic, lactic acids) are more inhibitory to growth compared with those acidified with mineral acids (e.g. hydrochloric, phosphoric acids) because organic acids can lower intracellular pH (following their translocation across fungal plasma membranes). Exposure to organic acids leads to cells

exhausting their energy (ATP) when endeavouring to maintain pH homeostasis through the activities of proton-pumping ATPase in the plasma membrane. This forms the basis of action of weak acid preservatives in **inhibiting the growth of food spoilage** fungi. Many filamentous fungi can **alter their local external pH** by selective uptake and exchange of ions (NO3 – or NH4 + /H+), or by excretion of organic acids such as oxalic acid.

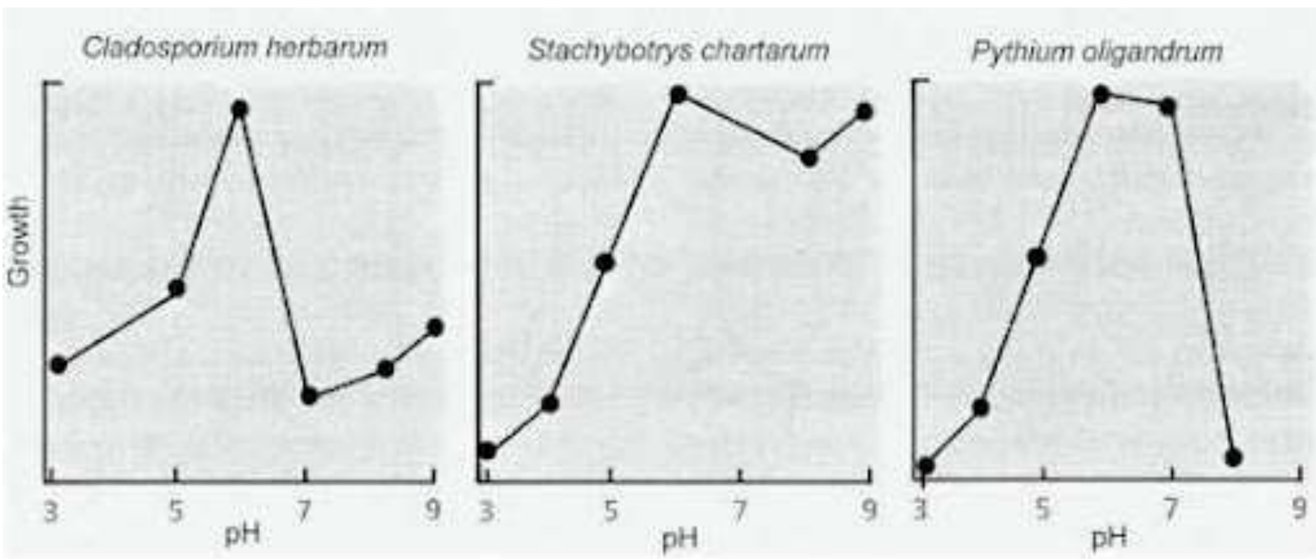

Fig.1 pH growth response curves of three representative fungi in laboratory culture; **a**, *Cladosporium herbarum*, **b**, *Stachybotrys chartarum*, **c**, *Pythium oligandrum*

- **Oxygen and fungal growth**: Most fungi are strict aerobes, in the sense that they require oxygen in at least some stages of their life cycle. Even *Saccharomyces cerevisiae*, which can grow continuously by fermenting sugars in anaerobic conditions, needs to be supplied with several preformed vitamins, sterols and fatty acids for growth in the absence of oxygen. *Saccharomyces* also requires oxygen for sexual reproduction. Having established these points, **we can group fungi into four categories in terms of their oxygen relationships**:

- **Many fungi are obligate aerobes**: their growth is reduced if the partial pressure of oxygen is lowered much below that of air. For example, growth of the take-all fungus (*Gaeumannomyces graminis*) of cereals is reduced. Aerobic fungi typically use oxygen as their terminal electron acceptor in respiration. This gives the highest energy yield from the oxidation of organic compounds.
- **Many yeasts and several mycelial fungi are facultative aerobes (e.g. *Fusarium oxysporum*, *Mucor hiemalis*, *Aspergillus fumigatus*)**: They grow in aerobic conditions but also can grow in the absence of oxygen by fermenting sugars. The energy yield from fermentation is much lower than from aerobic respiration, and the biomass production is often less than 10% of that in aerobic culture. However, a few mycelial fungi can use nitrate instead of oxygen as their terminal electron acceptor. This anaerobic respiration can give an energy yield at least 50% of that from aerobic respiration.
- **A few aquatic fungi are obligately fermentative**, because they lack mitochondria or cytochromes (e.g. *Aqualinderella fermentans*, *Oomycota*) or they have rudimentary mitochondria and low cytochrome content (e.g. *Blastocladiella ramosa*, *Chytridiomycota*). They grow in the presence or absence of oxygen, but their energy always comes from fermentation.
- **A few obligately anaerobic**: found in the digestive tracts of humans and other animals as well as in the first stomach of ruminants. Examples of obligately anaerobic fungal genera include the rumen fungi *Neocallimastix*, *Piromonas*, and *Sphaeromonas*.

- Obligate anaerobes convert nutrients into energy through anaerobic respiration or fermentation. **In aerobic respiration**, the pyruvate generated from glycolysis is converted to acetyl-CoA. This is then broken down via the TCA cycle and electron transport chain. **Anaerobic respiration** differs from aerobic respiration in that it uses an electron acceptor other than oxygen in the electron transport chain. Examples of alternative electron acceptors include sulfate, nitrate, iron, manganese, mercury, and carbon monoxide.
- **Fermentation** differs from **anaerobic respiration** in that the pyruvate generated from glycolysis is broken down without the involvement of an electron transport chain (i.e. there is no oxidative phosphorylation). Numerous fermentation pathways exist such as lactic acid fermentation, mixed acid fermentation, 2-3 butanediol fermentation where organic compounds are reduced to organic acids and alcohol.
- The energy yield of anaerobic respiration and fermentation (i.e. the number of ATP molecules generated) is less than in aerobic respiration. This is why facultative anaerobes, which can metabolise energy both aerobically and anaerobically, preferentially metabolise energy aerobically.

- **Water activity, a_w**
- **Light**