Biotechnology in the pulp and paper industry

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Life technologies, also known as **biotechnology**, are considered today as a promising tool for the transformation of biomass, such as wood, in paper pulps (unbleached and bleached).

In Nature, there exists a great variety of microorganisms, and more particularly fungi, which degrade the wood by means of their secretion products containing enzymes (Figure 1). Their study has logically oriented the research to the development of biotechnological techniques allowing the selective degradation of some wood components during the manufacture of paper pulps.

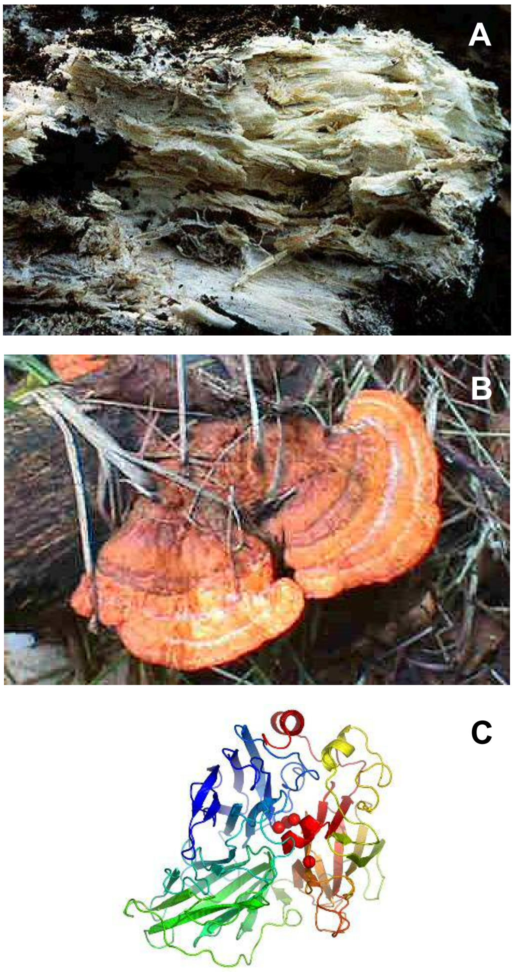

Figure 1: Some wood naturally degraded (A) by a white rot fungi (B) and 3D representation of an enzyme specialised in lignin biodegradation (C).

Two approaches are possible: one is based on the use of micro-organisms (mainly white rot fungi) and the other on the direct application of the enzymes, which degrade some of the wood chemical components (cellulose, hemicelluloses and lignin).

At the beginning of the 80’s, the main research subjects on biotechnology application in the pulp and paper industry concerned effluent treatments, mechanical pulp manufacture and cellulose hydrolysis. During the 90’s, considerable progresses were done for the use of enzymes specifically designed to facilitate the paper pulp bleaching. Today, the potential use of biotechnology is studied on all the subjects covering the whole value chain to transform biomass into papers (including recycling).

The paper pulp production aims to deconstruct the plant biomass (mainly wood) into fibres composed of cellulose. For obtaining such fibres, it is necessary to remove or modify other chemical components of the biomass such as lignin, hemicelluloses and extractives (resins, tanins). In Nature, some fungi are able to carry out the complete degradation of wood and other lignocellulosic biomass, due to a great variety of enzymes and chemicals produced in their metabolism. As mentioned above, either these microorganisms or their enzymes are used as biotechnological tools to aid lignocellulose degradation in the pulp and paper industry.

Fungi potentially used in the pulp and paper industry

An important family of fungi growing in Nature causing wood decay are the so called “wood-rotting fungi”, mainly classified as white rot and brown rot fungi depending on their biodegradation pattern. These fungi have the capacity of degrading or modifying the recalcitrant lignin polymer (one of the most important wood components together with cellulose and hemicelluloses). Among them, some white rot fungi are the most interesting for wood lignin degradation, yielding a white and light wood, in which the cellulose is preserved.

A great number of fungi have already been tested for the different steps of pulp manufacture, giving rise to several applications.

- ***Decrease in pitch content***:

During the stages of transformation of wood into fibres, some compounds generate the so-called pitch deposits at different locations of the utilised equipment and pulp, generating stops of the machines for cleaning and defaults into the paper sheet. These wood extractives are composed of lipophilic (resin acids, fatty acids…) and hydrophilic (some tannins and polyphenols) compounds. They are also responsible of the over-consumption of some additives used during pulping and papermaking. The pre-treatments of wood chips or logs with fungi allow to reduce the extractives content.
Today, one fungus is commercialised for reducing the pitch problem.

- ***Biopulping***:

Fungi can directly act on wood as logs, chips or sawdust. White rot fungi can grow on these substrates for 1 to 4 weeks, before their use in chemical and/or mechanical pulping processes.
The bio pre-treatment of wood allows a reduction of cooking and bleaching chemicals consumption, as well as of the electrical energy used in mechanical pulping, while causing and enhancement of paper pulp properties.

- ***Biobleaching***:

The bio-treatments applied directly on the pulp allow to increase the pulp brightness with lower bleaching chemicals charges, and consequently reducing the effluents load.

- ***Reduction of effluents toxicity***:

The biodegradation of compounds responsible of process effluents toxicity (more particularly resin acids) allow decreasing the eco-toxicity of the waste waters.

- ***Other applications***:

These concern the improvement of wood log debarking or the deinking of recycled papers.

Enzymes used in the pulp and paper industry

Enzymes are proteins able to speed-up biochemical reactions in Nature by means of their catalytic activity. The enzymes used in the bio-treatments of wood are naturally produced and secreted by microorganisms growing on wood, such as fungi and bacteria, although they are often overproduced in other organisms in order to obtain enough quantities and lower production costs.

The need to reduce the environmental impact of pulping processes has induced the development and utilization of some enzymatic systems. These can be used to replace some chemicals, due to their very specific activity. Four main families are identified based on their enzymatic activity (Figure 2):

- cellulases, including polysaccharide oxygenases, which degrade the cellulose;
- hemicellulases (xylanases and mannanases) which act on hemicelluloses;
- lignin-oxidizing enzymes (lignin, manganese and versatile peroxidases, laccases); and
- auxiliary enzymes, which react on the linkages between wood components, and contribute to the action of the other enzymes.

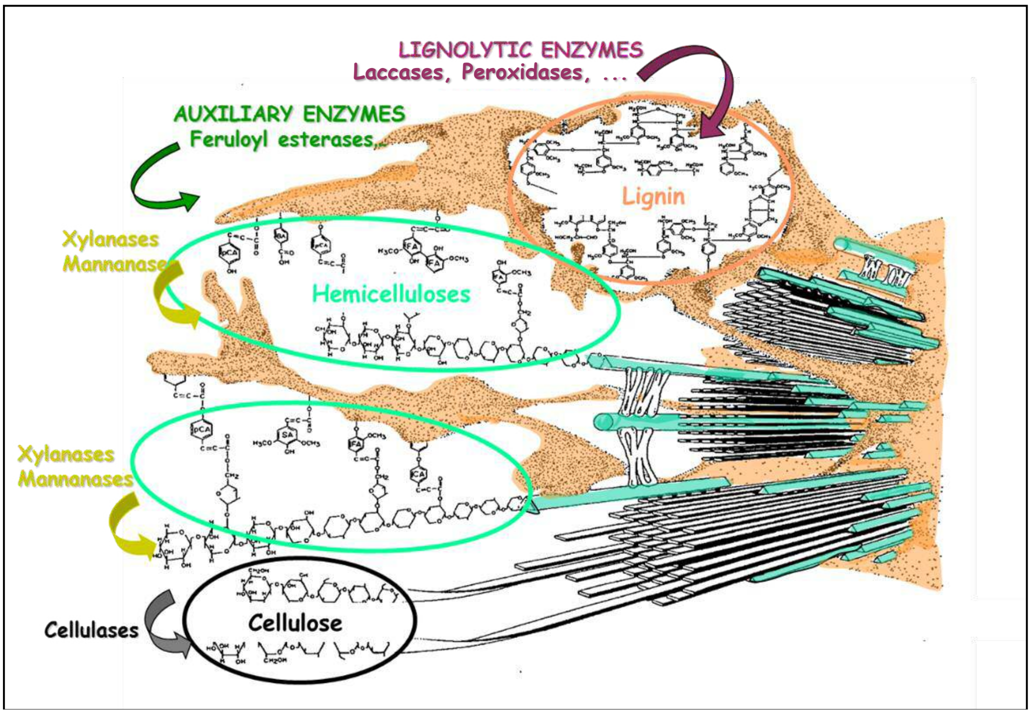

Figure 2: Main enzyme families acting on wood with potential biotechnological application.

The main applications of these enzymes in the pulp and paper industry are:

- Improvement of mechanical and chemical pulping (biopulping):

For the manufacture of paper pulps, enzymatic biopulping has been used in the mechanical pulping processes to reduce the electrical energy consumption by weakening the interfibres bonds. On the other hand, some pre-treatments with cellulases, hemicellulases, pectinases or laccases can facilitate kraft pulping (the predominant chemical pulping technology) of different wood species. These enzymatic treatments allowed enhancing delignification of chips and pulp bleaching by reducing the chemicals consumption.

- Improvement of refining ability of lignocellulosic fibres (biorefining):

Cellulases and hemicellulases have been applied on lignocellulosic fibres before refining. These treatments allowed reducing the electrical energy consumption to reach a given paper strength. However, the use of cellulases must be controlled in order to avoid the degradation of the fibre organization and to maintain the natural fibre strength properties needed for paper manufacture.

- Improvement of dissolving pulp properties:

Dissolving pulps are pulps with a very high cellulose content. Some treatments with cellulases can increase the reactivity of the pulp produced from softwoods or hardwoods. Besides, hemicellulases can also be employed to facilitate the removal of hemicelluloses in order to increase the cellulose content of the final pulp.

- Control of extractives in the pulp:

In order to reduce pitch deposits, enzymatic treatments with lipases and esterases (or laccases) can be applied. These treatments represent an alternative to wood chips aging (the conventional solution to reduce the extractives content). Added into the process waters, these enzymes allow the introduction of fresh wood into the pulping process, decreasing the pitch problem and avoiding the addition of minerals into the pulp.

- Improvement of pulp bleachability:

Pulp bleaching is one of the most interesting stages of paper pulp manufacture for applying enzymes. The main objective of bleaching is to brighten the cellulose fibres by acting on coloured residual lignin remaining in the fibres after cooking. Two approaches have been developed: one is to facilitate the lignin removal by acting on the lignin-carbohydrate linkages (with xylanases and mannanases), and the other is to act directly on the lignin (using laccases, peroxidases…). With laccases, the addition of small chemical compounds acting as redox mediators facilitates the oxidation of the most recalcitrant lignin structures. Today, the use of natural compounds derived from biomass as mediators is conceived as an alternative to reduce the environmental impact of synthetic ones.

The next two sections summarize the main biotechnological applications currently used or investigated in both chemical and mechanical pulping processes (Figure 3), followed by another section about other applications, such as the development of biorefineries, and some final conclusions.

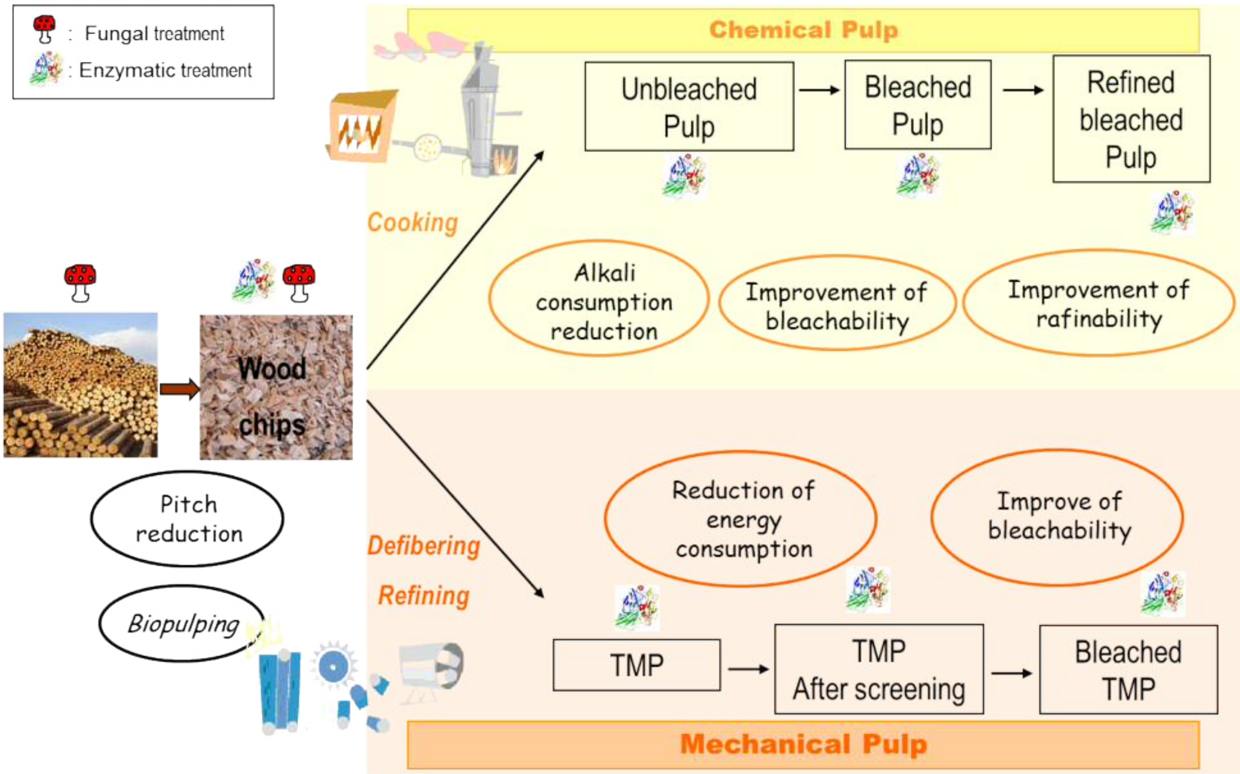

Figure 3: Utilisation of biotechnology in the pulp and paper industry: the main steps of the pulping processes, in which the enzymes or fungi can be used.

Application of biotechnology for the production of chemical pulps

Today, fungal pre-treatments of wood have been successfully assayed to facilitate the chemical cooking. As a result, pulping yield, kappa number (index indicating the residual lignin content in the fibres), fibre intrinsic strength, pulp refining ability and pulp hydrophilicity have been enhanced by such treatments (that can also contribute to pith mitigation and wood preservation during transport and storage).

For example, impregnation of *Pinus radiata* logs with *Pleurotus sp.*, a fungus found in forests, caused a mass loss after the treatment, due to lignin degradation.

Besides, a higher pulping yield and a lower kappa number were reached without any impact on the cellulose of the fibres, due the good selectivity of the fungus. Moreover, the resulting pulp could be bleached with lower chemicals charges and the paper quality of the pulp was significantly improved.

Concerning enzymatic treatments, the use of hemicellulases in chemical pulp bleaching gained interest for researchers since the middle of the 80's. The first industrial trials were carried out in Finland in 1988. Today, treatments with xylanases are the most expanded biotechnological ones in the pulp industry. Many chemical pulp mills have chosen to apply such enzymatic treatments at the beginning of the bleaching sequences. Their use allows reducing the charges of the chlorinated chemicals used for chemical pulp bleaching and therefore the environmental impact (decrease in organo-chlorinated compounds generation).

Many research results have also demonstrated the potential benefits of laccases and peroxidases in the chemical pulp bleaching at laboratory and pilot scales. The combination of xylanases and laccases in the pre-bleaching of chemical pulp is another potential application of interest.

Application of biotechnology for the production of mechanical pulps

A biopulping process based on the use of the fungus *Ceriporiospsis subvermispora* was developed at the end of the 80's for the manufacture of mechanical pulps. This biotreatment attained the 50-ton semi-commercial scale both in the US in the 90's and in South America ten years later. The main benefit was the reduction of the electrical energy consumption and the improvement of the pulp strengths. A gain of 7.5 € per ton of produced pulp was calculated.

On the other hand, a pre-treatment of poplar chips with xylanase before mechanical pulping has been developed, allowing 20% energy savings for the same pulp quality.

During the last 20 years, European research allowed developing different enzymatic pre-treatments on wood chips before mechanical pulping. Laccases in combination or not with a mediator have been successfully introduced in the TMP/CTMP process for reducing energy consumption. Pilot trials have demonstrated the interest of such a pre-treatment but, today, there are no industrial applications.

Other related applications

Further related biotech applications include the development of enzymatic processes during the production of cellulose microfibrils, which allow a good destructuring of the fibres while limiting energy consumption.

The application of enzymes able to act on lignocellulosic materials has also a great potential for turning pulp mills into biorefineries, which consist on the valorisation of all wood components besides cellulose. The role of the enzymes is to enable or facilitate the selective extraction of these components.

For the latter application, the enzymatic biocatalysts must be adapted to resist the harsh conditions employed in the pulp and paper mills, i.e. high pH and temperature. This is the reason why the European Project **WoodZymes** (www.woodzymes.eu) aims to develop and provide extremozymes for the wood transforming industry, that is, enzymes able to work at such extreme conditions of pH and temperature. The goal is to selectively valorise underutilised lignin and hemicellulose fractions of kraft pulp mills into biobased chemical building blocks for application in fibreboard and polyurethane insulation foams manufacture, as well as in paper making.

Conclusions

Biotechnology is a very promising approach for application in the pulp and paper processes, allowing energy savings, reduction of environmental impact and of production costs (e.g. reduction of chemicals consumption). The industrial production of enzymes is always in evolution and more stable enzymes are produced at lower cost.

The following table summarises some of the advantages and drawbacks of the use of biotechnology in the pulp and paper industry.

Advantages	Drawbacks
Clean technology: «Green Chemistry »	Limited stability of reagents
More ecological: reduction of chemicals consumption	Constraints for utilisation in terms of pH and temperature
Good selectivity	Price
No negative impact on pulp quality	Limited knowledge on the involved mechanisms

The use of enzymes has also great potential in the development of biorefineries, helping to extract molecules of interest and high added value from different biomasses, as a more selective and eco-friendly solution that the use of chemicals.

The latter topic is currently under investigation in the WoodZymes European Project, aiming to develop wood transforming extremozymes for application in kraft pulp mills. The next article of this series will address how enzymes can be "tailor-made" at the lab using state-of-the-art biotech tools. Stay connected to our website (www.woodzymes.eu) if you do not want to miss it!

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