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Research review paper

Industrial and biotechnological applications of laccases: A review

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Abstract

Laccases have received much attention from researchers in last decades due to their ability to oxidise both phenolic and non-phenolic lignin related compounds as well as highly recalcitrant environmental pollutants, which makes them very useful for their application to several biotechnological processes. Such applications include the detoxification of industrial effluents, mostly from the paper and pulp, textile and petrochemical industries, use as a tool for medical diagnostics and as a bioremediation agent to clean up herbicides, pesticides and certain explosives in soil. Laccases are also used as cleaning agents for certain water purification systems, as catalysts for the manufacture of anti-cancer drugs and even as ingredients in cosmetics. In addition, their capacity to remove xenobiotic substances and produce polymeric products makes them a useful tool for bioremediation purposes. This paper reviews the applications of laccases within different industrial fields as well as their potential extension to the nanobiotechnology area.

Keywords: Food industry; Industrial applications; Laccase; Nanobiotechnology; Pulp and paper industry; Textile industry

Contents

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1. Introduction

Although oxidation reactions are essential in several industries, most of the conventional oxidation technologies have the following drawbacks: non-specific or undesirable side-reactions and use of environmentally hazardous chemicals. This has impelled the search for new oxidation technologies based on biological systems such as enzymatic oxidation. These systems show the following advantages over chemical oxidation: enzymes are specific and biodegradable catalysts and enzyme reactions are carried out in mild conditions.

Enzymatic oxidation techniques have potential within a great variety of industrial fields including the pulp and paper, textile and food industries. Enzymes recycling on molecular oxygen as an electron acceptor are the most interesting ones. Thus, laccase (benzenediol: oxygen oxidoreductase; EC 1.10.3.2) is a particularly promising enzyme for the above-mentioned purposes. The laccase molecule is a dimeric or tetrameric glycoprotein, which usually contains four copper atoms per monomer distributed in three redox sites (Gianfreda et al., 1999). This enzyme catalyses the oxidation of ortho and paradiphenols, aminophenols, polyphenols, polyamines, lignins and aryl diamines as well as some inorganic ions coupled to the reduction of molecular dioxygen to water (Yaropolov et al., 1994; Solomon et al., 1996).

The reported redox potentials of laccases are lower than those of non-phenolic compounds, so these enzymes cannot oxidise such substances. However, it was shown that in the presence of small molecules capable to act as electron transfer mediators laccases were also able to oxidise non-phenolic structures (Bourbonnais and Paice, 1990; Call and Mücke, 1997), expanding, thus, the range of compounds that can be oxidised by these enzymes. Laccase-mediated systems (LMS) have been applied to numerous processes such as pulp delignification (Bourbonnais et al., 1997; Bourbonnais et al., 1998; Crestini and Argyropoulos, 1998; Li et al., 1999), oxidation of organic pollutants (Collins et al., 1996) and the development of biosensors (Kulys et al., 1997; Trudeau et al., 1997; Kuznetsov et al., 2001) or biofuel cells (Palmore and Kim, 1999). Several organic and inorganic compounds have been reported as effective mediators for the above-mentioned purposes. These include thiol and phenol aromatic derivatives, *N*-hydroxy compounds and ferrocyanide, respectively. Claus et al. (2002) found that the LMS enhanced dye decolourization and some dyes resistant to laccase degradation were decolourised. Lu and Xia (2004) have recently reviewed the applications of the LMS, which comprise pulp bleaching, textile biofinishing and environmental protection processes. However, despite that LMS has been studied extensively there are still unsolved problems concerned with mediator recycling, cost and toxicity.

Laccases have been reviewed several times in recent years, generally with emphasis on narrow aspects. The reviews by Messerschmidt (1993, 1997) and by Solomon et al. (1996) provide excellent summaries of the enzymology and electron transfer mechanism of the laccases and a book edited by Messerschmidt (1997) contains a series of articles dealing with different aspects of laccase kinetics and mechanism of action and the possible roles of this enzyme. The aim of this review is to highlight the potential industrial and biotechnological applications of laccase enzyme.

2. Potential industrial and biotechnological applications of laccase enzyme

Table 1 shows different applications of laccases in the last two decades. Laccases find applications within the following fields:

2.1. Food industry

Laccases can be applied to certain processes that enhance or modify the colour appearance of food or beverage. In this way, an interesting application of laccases involves the elimination of undesirable phenolics, responsible for the browning, haze formation and turbidity development in clear fruit juice, beer and wine.

Laccases are currently of interest in baking due to its ability to cross-link biopolymers. Thus, Selinheimo et al. (2006) showed that a laccase from the white-rot fungus *Trametes hirsuta* increased the maximum resistance of dough and decreased the dough extensibility in both flour and gluten dough.

Recently, Minussi et al. (2002) have described the potential applications of laccase in different aspects of the food industry such as bioremediation, beverage processing, ascorbic acid determination, sugar beet pectin gelation, baking and as a biosensor. However, they suggested that more studies of laccase production and immobilisation techniques at lower costs are needed to improve the industrial application of this enzyme.

2.2. Pulp and paper industry

The industrial preparation of paper requires separation and degradation of lignin in wood pulp. Environmental concerns urge to replace conventional and polluting chlorine-based delignification/bleaching procedures (Kuhad et al., 1997). Oxygen delignification