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Technology Prospecting on Enzymes: Application, Marketing and Engineering

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Abstract: Enzymes are protein molecules functioning as specialized catalysts for chemical reactions. They have contributed greatly to the traditional and modern chemical industry by improving existing processes. In this article, we first give a survey of representative industrial applications of enzymes, focusing on the technical applications, feed industry, food processing and cosmetic products. The recent important developments and applications of enzymes in industry are reviewed. Then large efforts are dedicated to the worldwide enzyme market from the demand and production perspectives. Special attention is laid on the Chinese enzyme market. Although enzyme applications are being developed in full swing, breakthroughs are needed to overcome their weaknesses in maintaining activities during the catalytic processes. Strategies of metagomic analysis, cell surface display technology and cell-free system might give valuable solutions in novel enzyme exploiting and enzyme engineering.

Mini Review Article

1. Introduction

Enzymes are natural catalysts. They are produced by living organisms to increase the rate of an immense and diverse set of chemical reactions required for life. They are involved in all processes essential for life such as DNA replication and transcription, protein synthesis, metabolism and signal transduction, *etc*. And their ability to perform very specific chemical transformations has made them increasingly useful in industrial processes.

Numerous reviews concerning different topics have been published, relating to strategies for enzyme engineering [1,2], biocatalyst in organic synthesis [3], biofuels production [4], and selected aspects of bioprocesses [5]. Representative processes of DSM, BASF, and Lonza have been discussed with respect to technological and economical perspectives of industrial enzyme applications [6]. In the following, this review would focus on three points. First, attentions are given to the current status of representative enzyme applications in the field of the technical applications, feed industry, food processing and cosmetics, with the aim of understanding the enzyme impact on modern chemical industry. Second, efforts are made to draw a simple and clear scenario about the industrial structure of global enzyme market. General environment of demand and supply of Chinese enzyme market is critically analyzed. To assess on a realistic and sound basis, large amounts of information has been collected from various sources including books, periodicals, patent literatures, company's annual report, market research report and internet webpage. Although enzyme preparations have been used by mankind over a long history, breakthroughs are needed to extend their uses in broader areas with more superior performance. Recent advancements in novel enzyme engineering are briefly introduced in the last part, especially for metagenomics, surface display techniques and cell free systems.

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2. Industrial Enzyme Applications

Enzymes are applied in various fields, including technical use, food manufacturing, animal nutrition, cosmetics, medication, and as tools for research and development. At present, almost 4000 enzymes are known, and of these, approximately 200 microbial original types are used commercially. However, only about 20 enzymes are produced on truly industrial scale. With the improved understanding of the enzyme production biochemistry, fermentation processes, and recovery methods, an increasing number of industrial enzymes can be foreseeable. The world enzyme demand is satisfied by about 12 major producers and 400 minor suppliers. Nearly 75% of the total enzymes are produced by three top enzyme companies, *i.e.* Denmark-based Novozymes, US-based DuPont (through the May 2011 acquisition of Denmark-based Danisco) and Switzerland-based Roche. The market is highly competitive, has small profit margins and is technologically intensive.

Table 1 gives the representative examples of enzyme applications based on different industrial sectors, and discusses the technical benefits in various fields. According to a research report from Austrian Federal Environment Agency [7], about 158 enzymes were used in food industry, 64 enzymes in technical application and 57 enzymes in feedstuff, of which 24 enzymes are used in three industrial sectors. Almost 75% of all industrial enzymes are hydrolytic enzymes. Carbohydrases, proteases and lipases dominate the enzyme market, accounting for more than 70% of all enzyme sales.

2.1 Enzymes in Technical Applications

Technical enzymes are typically used as bulk enzymes in detergents, textile, pulp and paper industries, organic synthesis and biofuels industry. Technical enzymes are valued at just over $1 billion in 2010 by several research associations. It is estimated that the technical enzymes market will increase at a 6.6% compound annual

Table 1. Enzyme applications based on fields [1,3,8-11].

Application fields		Enzyme	Technical benefits
Technical Applications	Pulp and paper industry	Amylases	Cleaving starch molecules to reduce the viscosity for surface sizing in coatings, but not used for dry strength agent additive.
		Lipases	Deinking and to control pitch in pulping processes.
		Cellulases	Improving softness by hydrolyzing cellulose in fibers, creating weak spots in fibers, making fibers flexible.
		Mannanases	Degrading the residual glucomannan to increase brightness.
		Laccases	Bleaching to improve brightness.
		β-xylanases	Enhancing pulp-bleaching process efficiency.
	Textile industry	Amylases	Desizing efficiently without harmful effects on the fabric.
		Cellulases	Removing the fuzz and microfibers to give the fabric a smoother and glossier appearance. Loosening the indigo dye on the denim to give a slightly worn look.
		Pectinases	Destabilizing the outer cell layer to improve fiber extraction.
		Laccases, glucoseoxidases	Creating bleaching agent in whiteness.
	Laundry Detergents	Proteases	Hydrolyzing protein-based stains in fabrics into soluble amino acids.
		Lipases	Decomposing fatty material, such as fats, butter, sauces and the tough stains on collars and cuffs.
		Amylases	Removing resistant starch residues.
		Cellulases	Modifying the structure of cellulose fiber to increase the color brightness and soften the cotton.
Food processing	Dairy industry	Chymosin, lipases, lysozymes	Cheese manufacturing.
		β-galactosidases, lactases	Breaking down lactose to glucose and galactose in milk processing to avoid lactose intolerance.
	Baking industry	α-amylases	Degrading starch in flours and controlling the volume and crumb structure of bread.
		β-xylanases	Improving dough handling and dough stability.
		Oxidoreductases	Giving increased gluten strength.
		Lipases	Improving stability of the gas cells in dough.
		Proteases	Reducing the protein in flour.
	Juice industry	Amylases, glucoamylases	Breaking down starch into glucose. Clarifying cloudy juice, especially for apple juice.
		Pectinases	Degrading pectins which are structural polysaccharides present in the cell wall. Increasing the overall juice production.
		Cellulases, hemicellulases*	Acting on soluble pectin hydrolysis and on cell wall components with pectinases Lowering viscosity and maintenance of texture.
		Laccase	Increasing the susceptibility of browning during storage.
		Naringinase and limoninase	Acting on compounds that cause bitterness in citrus juices
	Starch processing	α-amylases	Cleaving α-1,4-glycosidic bonds in the inner region of the starch. Causing a rapid decrease in substrate molecular weight and viscosity.
		Pullulanases	Attacking α-1,6- linkages, liberating straight-chain oligosaccharides of glucose residues linked by α-1,4-bonds.
		Neopullulanases, amylopullulanases	Acting on both α-1,6- and α-1,4-linkages.
		β-amylases	Cleaving α-1,4-linkages from non-reducing ends of amylose, amylopectin and glycogen molecules. Producing low-molecular weight carbohydrates, such as maltose and “β-limit dextrin”.
		Glucoamylases	Attacking α-1,4-linkages and α-1,6-linkages from the non-reducing ends to release β-d-glucose
		Isoamylases	Hydrolyzing α-1,6-linkages in glycogen and amylopectin.
		Glucose isomerases	Catalyzing isomerization of glucose to fructose
		Glycosyltransferases	Transferring a segment of a 1,4-α-D-glucan chain to a primary hydroxy group in a similar glucan chain to create 1,6-linkages. Increasing the number of branched points to obtain modified starch with improved functional properties such as higher solubility, lower viscosity, and reduced retrogradation.