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Research and application of biotechnology in textile industries in China

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Abstract

Textile industry is a conventional and pillar industry in China, which possesses a considerable proportion of the national economy. In recent years, special attention has been paid to the application of biotechnology in textile industries in China. As an interdiscipline between natural science and engineering science, textile biotechnology has much effect on China's textile industry. This paper summarizes current developments and highlights those areas where biotechnology might play an increasingly important role in China's textile industry as follows:

(1) Development of new types of textile fibers and polymers, such as Bt cotton naturally colored cotton, colored silk and silk gene-sequence, spider silk non-wovens, chitin fiber and chitosan derivatives, etc.
(2) Application of enzyme technology in textile wet processing, such as alkaline pectinase, PVA-degrading enzyme, cutinase and catalase used for cotton preparation, neutral cellulase for denim washing, transglutaminase for wool modification, protease for silk degumming as well as pectinase and hemicellulases for retting of bast fibers.
(3) Treatment of textile effluents with biotechnology.

Keywords: Biotechnology; Textile industries; Enzymes

1. Introduction

1.1. Overview of textile industries and textile biotechnology in China

The textile industry is traditionally regarded as a pillar industry in China, which has indeed made indispensable contribution to the national economic growth since the reform and opening policy went into effect in 1978. China ranks first in the world with its annual production capacity of cotton textiles, woollen fabrics, silk fabrics and chemical fibers, and processes 25% and 36% of the worldwide fiber output in 2004 and 2005, respectively. With the increase in China's population and rapid improvement in their living standards, textile demand rises in both quantity and quality; this is one of the main factors resulting in the rapid and sustainable growth of China's textile industry. Indeed, even with an amazing fiber production size (26,000 thousands tonnes in 2005) in China, about 80% of all the textile and apparel productions are sold in domestic market which has became the largest market of fiber consumption in the world, thus resulting in an increase of average fiber consumption level, from 4.1 kg/person in 1980 to 14 kg/person in 2005. In 2004 and 2005, the total textile industrial output values are US$ 199.316 billion and US$ 253.657 billion, which all have a ratio of 11% to gross domestic product (GDP) of China. The export value of China's textile industry reached a record US$ 117.535 billion in 2005, which accounted for 15.4% of China's total industrial export value and 24% of the global textile trade. In fact, China's export of textile and clothing has ranked first position in the world since 1995. Data comparisons of textile market shares between China and the rest of the world were presented in Table 1 [1–3].

China is the earliest country in the world using biotechnology. It is said that Chinese people mastered cultivation of crops and rational crop rotation early in the Stone Age, and in the later part

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Table 1
Global textile and clothing export values (in billion US$)

Country	Textile	Clothing	Total	Share (%)
Total	169.4	225.9	395.36	100
European Union (15 countries)	58.94	59.95	118.89	30.1
European Union (others)	26.37	19.04	45.41	11.5
China	26.9	52.06	78.96	20
Hong Kong	13.08	23.15	36.23	9.2
Hong Kong transit	12.33	14.95	27.28	6.9
USA	10.92	5.54	16.46	4.2
Turkey	5.24	9.94	15.18	3.8
Korea	10.12	3.61	13.73	3.5
India	6.51	6.46	13.73	3.5
Mexico	2.1	7.34	9.44	2.4
Pakistan	5.81	2.71	8.52	2.1
Indonesia	2.92	4.11	7.03	1.8

of the Stone Age, Chinese people were able to produce alcohol through fermentation technology. In 200 BC, flax dipping with anaerobic bacteria was recorded in "The Book of Songs", the ear1iest poem collection of China [4,5].

Nowadays, our lives are increasingly changed by the wide application of high and new technologies. Biotechnology is such a technology, which offers the textile industry the ability to reduce costs, protect the environment, address health and safety and improve quality and functionality. Especially as more and more strict laws and regulations on the wastewater discharge were established and implemented, there is a golden opportunity for biotechnology to replacing the traditional textile processing. In 2001, China had popularized some cleaner production techniques including biostonewashing of denim with cellulases and desizing of cotton fabrics with amylases to countrywide enterprises under the policy of the prevention and control of textile effluent pollution, the general plan and development of China's textile industry as well as the guide to the cleaner production of textile industry. There are 28 research priorities in the guideline of the 11th Five-Year (2006–2010) science and technology development program for textile industry, and among them, textile biotechnology such as environmentally friendly enzymatic treatments is included.

1.2. Research programs of textile biotechnology in China

There are many universities, research institutes and enterprises engaging in textile biotechnology in China. The earliest plan to promote biotechnology research was initiated in the beginning of the Seventh Five-Year Plan (1986–1990) when the first comprehensive National Biotechnology Development Policy Outline was issued (1990). Under this outline, a number of high-profile technology programs were launched after the mid 1980s. Some of the most significant programs included the 863 High-tech Plan, National Natural Science Fund, the Key Technologies R&D Program, and others. In 2001 and 2003, two projects focused on textile biotechnology (enzyme technology) were financially supported by the 863 Plan. Some projects focused on textile technology such as ramie retting, colored cotton and spider silk, etc. were funded by the National Natural Science Fund in the past few years. Additionally, some textile biotechnology projects were funded by the Key Technologies R&D Program, thereby enhancing the development of this new research field.

In recent years, special attention has been paid to the application of biotechnology in textile industries in China. As an interdiscipline between natural science and engineering science, textile biotechnology has much effect on China's textile processing. This paper summarizes current developments of textile biotechnology and highlights those areas where biotechnology might play an increasingly important role in China's textile industry as follows: (1) development of new types of textile fibers and polymers used in textile industries; (2) application of enzyme technology in textile processes; (3) treatment of textile effluents with biotechnology.

2. Application of biotechnology in textile materials

China began to investigate transgenic Bt (*Bacillus thuringiensis*) cotton in the 1980s and so far more than 46 varieties have obtained licenses for commercialization from the Chinese government since Bt-cotton was first commercialized in 1994. The cultivation areas of Bt-cotton amount to 8.47×10^6 hm^2 during the past 7 years and Bt-cotton has taken up 60% of cotton consumption for textile in China.

At present, China's Xinjiang Uygur Autonomous Region, a leading cotton producer of China and the largest natural colored cotton production base in the world, reaped 44,000 tonnes of colored cotton a year, accounting for 95% of the national total or 30% of the world's total. To date, China has owned eight strains of natural colored cotton including brown and green cotton. Researchers had been working to produce blue, red and black cotton by transferring an external colored gene into naturally grown white cotton with sophisticated genetic engineering technology [6].

Naturally colored silk in the shade of red, yellow, green, pink and orange has been successfully developed through genetically modified technology in China [7]. Another silk biotechnology in China is the drawing of the frame map of the silkworm genome, which was finished in 2003. This technique helps to understand the detailed knowledge of silkworm genes. Based on this information, we can breed new silkworms with high yield and quality to overcome silk's congenitally deficiencies such as tending to wrinkle and decolor or to obtain new types of silk.

The planting of flax in China was started in 1906. In 2004, China became the largest flax planting country in the world with a planting area of 34,600 acres. In the past 30 years, Chinese researchers always engaged in studies of flax biotechnology including anther culture, haploid breeding, utilization of somatic mutation, protoplasmic culture and gene transformation, but it must be noted that China lays far behind other advanced flax producing countries [8,9].

China has initiated the studies on the synthesis of spider silk proteins by using gene recombination, technology since the turn of the century. Some primary results have been obtained. For instance, tractile fiber protein has been successfully synthesized by using *Bacillus coli*.

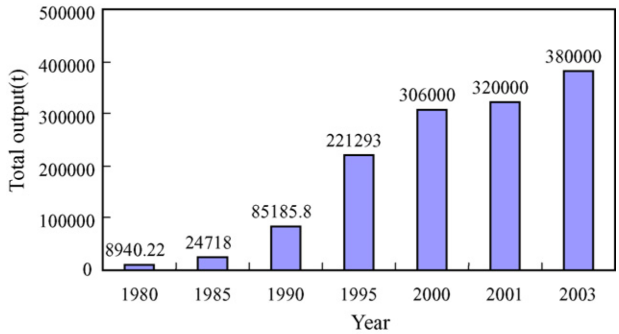

Fig. 1. Variation of total enzyme output in China.

Chitin, a biopolymer found in the exoskeleton of insects and marine invertebrates, has been developed in China. Chitin fiber has gone into mass production and mainly used as medical textiles. Chitin and its derivatives have been commonly researched to be functional finishes for textiles in China due to their excellent multifunctional properties such as antimicrobial, antistatic and anticrease.

3. Application of enzymes in textile wet processing

3.1. Overview of China's enzyme industry

The type and total output of enzymes produced in China amount to 30 and more than 380,000 tonnes in 2003, respectively [10,11]. Fig. 1 shows the variation of enzyme output in China in 1980–2003. By now, the enzyme products of China are mainly sold domestically, taking up only less than 15% in the whole production in China's enzymes industry and 5% share in world market. China's rapid increasing enzyme consumption markets have attracted some foreign companies such as Novozymes and Genercor to set up research and development centers or production bases in China. In contrast, although there are more than 100 enzyme factories in China, they are all medium and minor enterprises and mainly produce several enzyme preparations including saccharifying enzyme, alfa-amylase and protease, which possess around 95% of China's local enzyme output. Data on the consumption of enzyme in China and the rest of world were shown in Table 2. Although the enzyme consumption in textile industry in China is very limited, its great application potential could be expected because of China's enormous scale of textile industry [11].

Table 2
Data on the consumption of enzyme

Industry	Share (%)	
	China	The rest of world
Detergent	16.1	38.0
Starch	74.8	11.0
Textile	2.3	9.0
Others	6.8	42.0

3.2. Commercialization and current research of enzymatic treatments in textile wet processing

3.2.1. Commercialization of enzymatic treatments

To date, China has realized the production in industrial scale of desizing of cotton fabrics with amylases, bio-cleanup of residual hydrogen peroxide with catalases and biostonewashing of denim with cellulases.

Amylase BF-7658, a mesothermal alfa-amylase from *Bacillus* stain developed independently in the 1960s was employed in China's textile industries for quite a long time. In recent years, enzymatic desizing was restricted to a certain degree and the application decreased compared to before because of the rich use of polyvinyl alcohol (PVA) size in cotton sizing in China. However, it can be reasonably expected that the enzymatic desizing will be taken seriously again because of the increasing application of thermostable amylases and the environmental pollution problem of PVA. Indeed, more and more high-performance modified starch sizes, which can partially or totally replace PVA size, are utilized for textile sizing in China.

The application of catalase for the elimination of hydrogen peroxide residues after bleaching of cotton fabrics has been quickly and widely popularized in China textile industries since the late 1990s. Catalase has a rich source because it almost exists in all aerobionts. The commercially available catalases are derived from animal viscera such as bovine liver and fermentation of microorganisms in China market. The thermo-alkali-stable catalases produced from the microorganisms have evident advantages over those derived from bovine liver and are more suitable for textile bio-cleanup. In recent years, a great deal of research on catalases has being carried out by some research institutes in China. For example, the thermo-alkali-stable catalase from *Thermoascus aurantiacus* WSH 03-01 developed by Southern Yangtze University has gone into mass production in China [12].

Stoneless washing (i.e. biostonewashing) of denim with acidic and neutral cellulases provided by several famous enzyme preparation companies such as Novozymes, Genercor, Cognis, Rotta and Bayer, has been widely applied in China. Biostonewashing was first introduced to China's textile industry in the mid 1990s and spread to the whole country at the turn of the century. Nowadays, its application is global and it provides an excellent example of how rapidly and completely a biotechnology-based process can transform an industry. It should be noted that the laccase has been introduced to China, but its application is limited because of the cost. China has produced some acidic cellulases including some genetically modified products used for the biostonewashing of denim, whereas so far the neutral cellulose is not commercialized. The screen and culture of highly active bacterial strain of neutral cellulase as well as its extractive technique undertook by Southern Yangtze University were financially supported by the 10th Five-Year Key Technologies R&D Program [13]. The work has made great advances and lays a strong foundation for the localization of neutral cellulase.

Table 3
Typical microbial strains for bast retting developed in China

Code	Microbial	Property	Retting fiber	Technological conditions	Developer
GT-17	*Bacillus subtilis*	Aerobic	Ramie		Huazhong Agriculture University
T85-260	*Erwinia carotovora*	Aerobic	Ramie	35–37 °C, soak 6–7 h, wetting 5–6 h	Institute of Bast Fiber Crops, Chinese Academy of Agricultural Sciences
T66	*B. subtilis*	Aerobic	Ramie	42 °C, 6 h then 55 °C, 1–1.5 h, aeration, liquor ratio: less than 15:1	Institute of Bast Fiber Crops, Chinese Academy of Agricultural Sciences
T55	*B. subtilis*	Aerobic	Ramie	42 °C, 6 h, aeration	Institute of Bast Fiber Crops, Chinese Academy of Agricultural Sciences
Ke34/Le10	*B. subtilis*	Aerobic	Flax	5% inoculum concentration, 35 °C/25 °C, 60 h/54 h	Heilongjiang Province Agriculture Academy of Science and Northeast Agricultural University
T1163	*Bacillus polymyxa*	Anaerobic	Kanaf, jute	35 °C, 36 h, liquor ratio: 15:1–30:1	Institute of Bast Fiber Crops, Chinese Academy of Agricultural Sciences

3.2.2. Current research of enzymatic treatments in textile wet processing

The increasing environmental legislation and burden on the textile industries in China have forced textile enterprises to seek environmentally friendly processes to replace conventional preparation of cotton fabrics. The latter produces severe pollution problems and it is said that around 75% of the organic pollutant level arising from textile finishing is derived from the pretreatment of cotton goods in the previous report. Much of the work in the area of cotton biopreparation has been focused on investigating the utility of various enzymes. In China, Southern Yangtze University started an integrated research on the preparation and application of textile biological catalases used for cleaner production in textile industries in 2001–2005, which was financially supported by the 863 plans. This work focused on the preparation and application for cotton pretreatment of alkaline pectinase, cutinase, PVA-degrading enzyme and catalase. The high-yielding microbial strains of these enzymes with own intellectual property rights were obtained. Through the investigation of the optimization and control of fermentation, we improved significantly the production capacity of these enzymes. Especially in the preparation of alkaline pectinase and catalase, we have successfully finished the industrial-scale tests of enzyme production and involved field application in textile industries.

Proteases were once used for wool anti-felting in the past few years in China, but no breakthroughs were reached as other countries. Transglutaminase (TG, protein–glutamine–glutamyltransferase) has recently acquired interest due to its attractive potential application in textile industries. However, the extremely high price of tissue transglutaminase (about 80 US$ per unit) makes it impossible to apply tissue transglutaminase on an industrial scale and leads to the search for microbiological sources. To achieve commercialization of TG, studies including the screening of microorganisms, scaled-up cultivation and downstream-process optimization, which were financed by the national 10th Five-Year Plan and the national natural science fund, have been continually performed in Southern Yangtze University [14]. The beneficial function of TG in the anti-felting and elastomeric finishing of wool fabrics was revealed and further investigations are still performed.

Degumming of silk fabrics with neutral and alkaline proteases is employed in a limited number of China's factories because of the lower enzymatic activities and indispensable pretreatment and subsequent finishing scouring which resulting in a long and complex process flow. In recent years, along with the increasing advances in biotechnology, some high-performance proteases are applied in silk degumming. The technological processes include one-bath and two-bath (pretreatment followed by protease treatment) enzymatic degumming, which have a relatively short process time and an improved degumming efficiency.

China has started manual inoculation microbial retting (biodegumming) of bast fibers including ramie, linen, kanaf, hemp and jute since the 1980s [5]. Some high active strains used for microbial retting are listed in Table 3. To date, conventional retting of flax such as water retting and dew retting is still adopted in China, whereas enzyme retting has also been investigated. Several enzyme preparations from foreign companies, such as Novoflaxzyme and Ultrazyme from Novozymes, were once introduced to the research of flax retting and positive results were obtained. However, the high cost property of enzyme retting of flax blocks its large-scale popularization in China.

4. Biological treatment techniques for textile effluent

I t is well known that vast amounts of water, energy and chemicals are consumed in the textile industry. It is estimated that annually textile wet processing produce around 0.65 billion tonnes of wastewater in China, which may take up 80% of total textile effluent disposal. There are many technologies currently available for treating wastewater from the textile industry. However, textile effluent is mainly treated by using the biological methods or combination of the biological and chemical methods in China. The aerobic treatments, which include activated sludge process and biofilm method, are commonly employed. Typical biological treatment of textile effluent is the anaerobic–aerobic process and screen and application of high performance decolorizing bacteria and PVA-degrading bacteria [15–17].

Along with the development of synthetic fibers and the advance in textile wet processing, a great deal of organic compounds with worse biodegradability, such as PVA and some new-type auxiliaries, came into textile effluent, which improved its treatment difficulty. Enhancements of biological treatment techniques, such as bioaugmentation, immobilized microorganism and microorganism activity enhancement, are studied by

Chinese researchers with a view to improve the production efficiency of wastewater treatment systems. The most common bioaugmentation is to putting the microorganisms which have excellent capacity of decomposition to targeted pollutants. In addition, constructing and applying high-efficiency genetic engineering microorganism is also an effective bioaugmentation technique.

The immobilized microbial techniques using porous silicate, quartz sand, glutin, agar, PVA, attapulgite clay and plastic ring as carriers have been investigated detail in China since the 1980s. These treatments can greatly reduce reaction time and improve percent of decolorization. However, on the whole this processing is still at the research stage and its industrialized application should be the focal point of future studies.

Additionally, the effects of trace metallic compound such as ferric hydroxide, manganese chloride and manganese oxide on textile biological treatment were also be investigated and positive results were obtained. This may ascribe to the enhancement of the decolorization activities of microorganisms.

5. Conclusions

The Outline of the 11th Five-Year Plan (2006–2010) of China has clearly put forward some restrictive requirements involved industrial production: (1) resources utilization efficiency will be improved considerably while energy consumption of per unit GDP will be lowered by 20%; (2) water consumption will be decreased by 30%; (3) the total emission volume of major pollutants will be reduced by 10%. These are all closely interrelated to textile industry, especially textile wet processing sector. Recent studies on the contribution of biotechnology in the industrial sector show that biotechnology in textile industry reduce water usage and energy demand for bleaching (bio-cleanup) by about 9–14% and 17–18%, respectively, or could cut water consumption by as much as 30–50% (bioscouring) and cost associated with water usage and air emission by about 50–60% (biostonewashing). Evidently, the application of textile biotechnology can result in cleaner processes that produces less waste and use less energy and water and is one of the most promising new approaches to pollution prevention, resource conservation and cost reduction.

To date, more and more attentions have been focused on textile biotechnology, in particular enzyme technology in China. Genetic engineering offers new opportunities to produce modified or new enzymes with better properties. However, so far only partial success was achieved using existing commercial enzyme preparations due to the recalcitrant nature of some of the components and the process was found to be too slow and therefore uneconomic for current applications. Undoubtedly, the use of genetically modified microbial enzymes of commercial importance can be expected to expand into many other areas of the textile industry thus replacing existing chemical or mechanical processes in the not too distant future. To sum up, the application of biotechnology in textile industry is a good solution for the cleaner production technology compared with conventional procedures which have severe pollution problems, and biotechnology will gain greater success in textile industry.

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