Application of Genetic Engineering and Enzymes in Textiles

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Review of application biotechnology in textiles includes potential for new industrial processes, renewable raw materials, genetic engineering and effluent management. Enzymes are not alive themselves but are complex chemical catalysts. Genetic engineering is one of the techniques in modern biotechnology, which directly modifies the power of DNA molecule. The protein molecules, such as, monoclonal antibodies have amazing ability of active even at low concentrations. DNA probes are, another technique being now identified not only to speciality animal hairs but also for other natural fibres like cotton. Applications of biosensitive materials into textiles are mainly used to produce intelligent filter media, smart textiles, and protective clothing. Fibre, fabric preparation and finishing are the other important area where biotechnology can be widely used. Treatment of silk-cellulosic blend is claimed to produce some unique effects. Microbial processes have been used to treat the effluent comes out from the textile industry. The development based on a 3D-biomat of knitted polyester monofilament is used as a support for the microorganism. Using biotechnological process routes, several possibilities exist for producing entirely new fibres. R&D work is under progress in genetically modified micro-organisms and dyestuffs for the textile field.

Keywords: Genetic engineering; Monoclonal antibodies; Biosensors

INTRODUCTION

Biotechnology is the application of living organisms and their components to industrial products and processes. In 1981 the European federation of biotechnology defined Biotechnology as 'Integrated use of Biochemistry, Microbiology and Chemical Engineering in order to achieve the technological application of the capacities of microbes and cultured tissue cells'.

The rapid developments in the field of genetic engineering have given a new impetus to biotechnology. This introduces the possibility of 'tailoring' organisms in order to optimize the production of established or novel metabolites of commercial importance and of transferring genetic material (genes) from one organism to another. Biotechnology also offers the potential for new industrial processes that require less energy and are based on renewable raw materials. It is important to note that biotechnology is not just concerned with biology, but it is a truly interdisciplinary subject involving the integration of natural and engineering sciences. Defining the scope of biotechnology is not easy because it overlaps with so many industries, such as, the chemical industry or food industry being the majors, but biotechnology has found many applications in textile industry also, especially in genetic engineering, textile processing and effluent management.

FARMING WITH BUGS

Simple cellular organisms, such as, yeast have been used for millennia, knowingly or otherwise, to make bread, beer and wine. Most industrial applications of biotechnology are still based upon fermentation processes using bacteria and enzymes to digest, transform and synthesize natural materials from one form into another. It is not surprising perhaps that biotechnology is often described as 'farming with bugs'.

For example, the active agent in many transformation processes is an enzyme rather than the cellular living organism itself. Enzymes are not alive themselves but are complex chemical catalysts, which can, in principle, be produced by a number of different methods, including non-biological synthetic routes.

THE SYSTEMATIC APPLICATION OF BIOLOGICAL SCIENCE

The contribution of science has been to understand to a much greater extent what exactly are the active components and mechanisms of the 'Bugs' and their derivatives and therefore to begin to control, manipulate and reproduce their capabilities in a more systematic and intelligent fashion.

Modern biotechnology has also brought forward a number of techniques, which do not rely on microbes and enzymes at all, but which directly modify the power of DNA molecule first and foremost among these is genetic engineering.

GENETIC ENGINEERING

With an improved understanding of how different genes are responsible for the various characteristics and properties of a living organism, techniques have been developed for isolating these active components (in particular, the DNA which carries the genetic code) and manipulating them outside of the cell.

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This paper was received on August 11, 2003. Written comments on the paper will be received till May 31, 2004.

The next step has been to introduce fragments of DNA obtained from one organism into another, thereby transferring some of the properties and capabilities of the first to the second. For example, scientists working for the leading enzyme producer, Novo of Denmark, discovered that an enzyme produced in minute quantities by one particular fungus had very desirable properties for dissolving fats. The relevant genes where 'spliced' into another micro-organism which was capable of producing the desired enzyme at much higher yield.

Genetic engineering methods are being investigated for their potential to produce new kinds of textile fibres. The systems fall into two main groups. There are those systems that can produce monomeric protein molecules in solution from appropriately engineered genes and include expression in bacteria, cell cultures or in the milk of transgenic animals such as goats or sheep. The protein monomers are then isolated from the chosen system and spun and drawn into fibres. The other approach is to modify keratin fibres such as wool by expressing other proteins in the internal components by trangenesis.

Biopesticides based on a strain of soil bacteria known as Bt are already being used for control of caterpillar and beetle pests in a wide variety of fruits, vegetables and crops. More stable, longer lasting and more active Bts are now being developed for the suppression of loopers, bollworms and budworms in cotton. The next stage will be to introduce greater insect and herbicide resistance by direct genetic engineering of the cotton plant itself.

Practical results achieved so far include development of a cotton fibre with 50% greater strength than its 'parent'. Coloured cottons are also being developed, not only by conventional genetic selection but also by direct DNA engineering to produce, for example, deep blue cotton for denim production. The prospect is even being held out of encouraging natural polyesters such as polyhydroxy butyrate (PHB) to grow within the central hollow channel of the cotton fibre, thereby creating 'natural' polyester-cotton.

MONOCLONAL ANTIBODIES

Monoclonal antibodies are protein molecules with an amazing ability to 'recognize' specific substances, even at extremely low concentrations. They were first developed for use in medicine to detect and target cancer cells so called 'magic bullet approach'; they have also been used for pregnancy testing.

Recently, Biocode Company has developed monoclonal antibodies as very sensitive marking tool for the prevention of counterfeiting. The markers themselves are cheap and safe substances, which can be applied to foodstuffs, drinks and textiles in concentrations of a few parts per million or less. The 'codes' embodied in these markers are completely secure but can readily be detected by customs or trading standards inspectors using simple equipment in the field.

The technology has already been evaluated for the marking of branded denims. Methods have been perfected for use in nylon and acrylic resins and markers can also be incorporated into dyestuffs or applied to surfaces using ink jet printers.

DNA PROBES

DNA probes are another technology, which has grown out of genetic engineering. Short pieces of DNA can be designed to stick very specifically to other pieces of DNA and thereby, to help identify target species. The technique can be applied, for example, to distinguish Cashmere from Wool and other goat fibres.

The initial impetus for application of DNA probes in the textile industry has come from importers and processors of specialty animal hairs who have seen a surge in trading and labelling fraud, especially in the wake of recent high fibre prices. Now, similar probes are being identified to distinguish between cotton, ramie, kapok, coir, flax, jute and hemp.

BIOSENSORS

Another way in which biological systems can be used as extremely sensitive analytical and control tools is biosensors. These employ some change produced by very small quantities of biologically active agents to measure and therefore, in principle, to control chemical and physical reactions.

BTTG has been working on the use of certain fungi, which are capable of absorbing and concentrating heavy metal ions such as lead, copper and cadmium. Resultant changes in the conductivity and dielectric properties of the fungi can be used to measure these species in a process or effluent stream relatively cheaply and easily. Application can be envisaged which incorporate biosensitive materials into textiles, for example, to produce 'intelligent' filter media or protective clothing which detects as well as protects against chemicals, gases and biological agents.

APPLICATIONS TO PROCESSING

The use of enzymes in textile processing and after care is already the best established example of the application of biotechnology to textiles and is likely to continue to provide some of the most immediate and possibly dramatic illustrations of its potential in the near-to medium-term future.

Fibre Preparation

Linen is a cellulosic fibre obtained from the flax plant. These fibres are formed in the cortex between the lignified core and the outer layers of the stem, they are separated from the stems by retting, in which matrix components, mainly pectin and lignin are removed and the fibres are separated. Recently, considerable efforts have been put to use enzymes in the retting process to control the process to produce linen fibres of consistent quality. Pre-treatment of the flax with sulphur dioxide gas brings about sufficient breakdown of the woody straw material to speed up enzyme retting whilst preventing excessive bacterial or fungal deterioration of the fibre.

The carbonization process in which vegetable matter in wool is degraded by treatment with strong acid and then subjected to mechanical crushing can, in principle, be replaced by selective enzyme degradation of the impurities.

Fabric Preparation

Desizing using amylase enzymes has been well established for many years. However, there is still considerable scope for improving the speed, economics and consistency of the process, including the development of more temperature stable enzymes as well as a better understanding of how to characterize their activity and performance with respect to different fabrics, sizes, and processing conditions, *eg*, for pad batch as opposed to jigger desizing.

The current application in the textile industry involves mainly hydrolases and now to some extent is Oxidoreductase. The Tables 1 and 2 exemplify such textile applications.

Another desirable development would be enzymes capable of destroying honeydew sugars, insect secretions that cause stickiness and severe processing problems for cotton spinners.

An already established application is the use of catalase enzymes to breakdown residual hydrogen peroxide after, for example, pre-bleach of cotton that is to be dyed a pale or medium shade. Reactive dyes are especially sensitive to peroxide and currently require extended rinsing and/or use of chemical scavengers. The enzyme catalase is added after oxidative bleaching and allowed to react for 15 minutes at 30° C-40° C. It degrades the residual peroxide in water and oxygen.

The results obtained were compared with the conventional process and it was found that the outcome of the enzymatic process was excellent. The best suitable conditions are the temperature range of 20° C-60° C, pH 5-10 and the application time is 10 min to 15 min.

Table 1 Application of hydrolase enzyme in fabric preparation

Sl No	Enzyme Name	Substrate Attacked	Textile Application
1	Amylase	Starch	Starch desizing
2	Cellulase	Cellulose	1. Stone wash-Bio-polishing (Bio singeing) 2. Bio finishing for handle modification 3. Carbonization of wool
3	Pectinase	Pectin	Bio scour replacing caustic
4	Catalase	Peroxides	*In situ* peroxide decomposition without any rinse in bleach bath
5	Proteases	Protein molecules or peptide bonds	1. Degumming of silk 2. Bioantifelting of wool
6	Lipases	Fats and oils	Improve hydrophilicity of PET in place of alkaline hydrolysis

Table 2 Application of oxidoreductase in fabric preparation

Sl No	Enzyme Name	Substrate Attacked	Textile Application
1	Laccase	Colour chromophore and pigments	1. Discoloration of coloured effluent 2. Bio-bleaching of lignin containing fibres like kenaf and jute 3. Bio-bleaching of indigo in denim for various effects
2	Peroxidases	Colour chromophore and pigments	Bio-bleaching of wood pulp
3	Glucose oxidases	Pigments	*In situ* generation of H_2O_2 and bio-bleaching of cotton
4	AZO reductase	Colour chromophore and pigment	Discoloration of AZO dyes effluent
5	Peroxidase ostreatus	Colour chromophore and pigments	Discoloration of Remazol of basic dye effluent

FINISHING

Biostoning and the closely related process of bio-polishing are perhaps attracting most current attention in the area of enzyme processing. They are also an excellent illustration of how different industry structural and market considerations can affect the uptake of enzyme technology.

Conventional stone washing uses abrasive pumice stones in a tumbling machine to abrade and remove particles of indigo dyestuff from the surfaces of denim yarns and fabric. Cellulase enzymes can also cut through cotton fibres and achieve much the same effect without the damaging abrasion of the stones on both garment and machine. Disadvantages can include degradation of the fabric and loss of strength as well as ‘back staining’. A slight reddening of the original indigo shade can also occur. Now processors are learning to play more sophisticated tunes such as achieving a peach skin finish by use of a combination of stones and natural cellulase.

Bio-polishing employs basically the same cellulose action to remove fine surface fuzz and fibrils from cotton and viscose fabrics. The polishing action thus achieved helps to eliminate pilling and provides better print definition, colour brightness, surface texture, drapeability, and softness without any loss of absorbency.

Bio-polishing can be used to clean up the fabric surface after the primary fibrillation of a peach skin treatment and prior to a secondary fibrillation process which imparts interesting fabric aesthetics. A weight loss in the base fabric of some 3%-5% is typical but reduction in fabric strength can be controlled to within 2%-7% by terminating the treatment after about 30 min-40 min using a high temperature or low pH 'enzyme stop'. One area that still poses problems is that of tubular cotton finishing. Here, the fibre residues tend to be trapped inside the fabric rather than washed away.

WOOL PROCESSING APPLICATIONS

The international wool secretariat (IWS) together with, Novo, been developing the use of protease enzymes for a range of wool finishing treatments aimed at increased comfort (reduced prickle, greater softness) as well as improved surface appearance and pilling performance. The basic mechanisms closely parallel those of bio-polishing. The improved enzyme treatments will allow more selective removal of parts of the wool cuticle, there by modifying the luster, handle and felting characteristics without degradation or weakening of the wool fibre as a whole and without the need for environmentally damaging pre-chlorination treatment.

OTHER PROTEASE APPLICATIONS

Protease enzymes similar to those being developed for wool processing are already being used for the degumming of silk and for producing sand washed effects on silk garments. Treatment of Silk-Cellulosic blend is claimed to produce some unique effects. Proteases are also being used to wash down printing screens after use in order to remove the proteinaceous gums, which are used for thickening of printing pastes.

TEXTILE AFTER-CARE

Enzymes have been widely used in domestic laundering detergents since the 1960s. Some of the major classes of enzymes and their effectiveness against common stains are summarized in Table 3.

Early problems of allergic reactions to some of these enzymes have now largely been overcome by the use of advanced granulation technology. Modern enzyme systems have reduced the use of sodium perborate in detergents by 25% along with the release of harmful salts into the environment.

However, enzymes still have to make a corresponding impact upon the commercial laundering market. One of the problems here has been the level of investment in 'continuous-batch' or tunnel washers. These typically afford a residence time of 6 min-12 min which is not long enough for present enzyme systems to perform adequately. More efficient methods of 'enzyme kill' are also required because of the extent of water recycling in modern washers.

Table 3 Types of enzymes and their effectiveness against various stains

Enzyme	Effective for
Proteases	Grass, Blood, Egg, Sweat stains
Lipases	Lipstick, Butter, Salad oil, Sauces
Amylases	Spaghetti, Custard, Chocolate
Celluloses	Colour brightening, Softening, Soil removal

Further developments in the field of textile after-care may include treatments to reverse wool shrinkage as well as alternatives to dry cleaning.

CARING FOR THE ENVIRONMENT

Natural and enhanced microbial process have been used to treat waste materials and effluent streams from the textile industry. Conventional activated sludge and other systems are generally well able to meet BOD and related discharge limits on most cases. The industry faces some specific problems like colour removal from dyestuff effluent and handling of toxic wastes including PCPs and heavy metals.

The synthetic dyes are designed in such a way that they become resistant to microbial degradation under the aerobic conditions. Also, the water solubility and the high molecular weight inhibit the permeation through biological cell membranes. Anaerobic processes convert the organic contaminants principally into methane and carbon dioxide, usually occupy less space, treat wastes containing up to 30 000 mg/l of COD, have lower running costs and produce less sludge.

A novel approach to promoting aerobic degradation in contaminated lagoons and preventing the development of malodorous and unpleasant anaerobic processes. The development based on a 3-D 'biomat' of knitted polyester monofilament is used as a support for the micro-organisms. The mat is stable and resistant to compression; its open supporting structure counteracts the build-up of anaerobic sludges on the bottom of the lagoon.

NEW FIBRE SOURCES

Several possibilities exist for producing entirely new fibre materials, so called biopolymers, using biotechnological process routes, Naturally occurring polyester, PHB is produced by bacterial fermentation of a sugar feed stock and commercially available as 'Biopol'. The polymer is stable under normal conditions but biodegrades completely in any microbially active environment. Other biopolymers with textile potential include polylactates and polycaprolactones, which are investigated for medical applications.

Bacterial Cellulose

The speciality papers and nonwovens are produced based on bacterially grown cellulose fibres these are extremely fine and resilient and are used as specialized filters, odour absorbers and reinforcing blends with aramids.

Genetically Modified Micro-Organisms

Attempts have been made to transfer certain advantageous textile properties into micro-organisms where they can be more readily reproduced by bulk fermentation processes. The spider DNA is transferred into bacteria with the air of manufacturing proteins with the strength and resilience of spider silk for use in bulletproof vests.

DYESTUFFS AND INTER MEDIATES

Attempts have been made to synthesize bacterial forms of indigo as well as fungal pigments for use in the textile industry.

Certain micro fungi are capable of yielding up to 30% of their biomass as pigment. Potential non-textile applications include food industry colorants

CONCLUSION

This note of caution needs to be echoed across the whole spectrum of biotechnology developments. Although biological systems after many attractive possibilities and new approaches to all sorts of problems and needs, considerable advances are still being made in 'conventional' technologies, such as, catalysis, chemical synthesis and physical fibre modification which need to be kept in perspective. There is also still great concern in society about the unbridled advance of biotechnology, especially with regard to the modification of natural species with possible unknown long-term consequences.

ACKNOWLEDGEMENT

The authors thank the management of the PSG College of Technology, Coimbatore, for providing the infrastructure to carry out this work. We also thank Dr Vijayarangan, Principal, PSG College of Technology, Coimbatore, for his continuous encouragement. Authors are also very grateful to Dr A Venkatachalam, Head, Department of Textile Technology, PGS College of Technology, Coimbatore, for his valuable guidance and support.

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