The Impact of Biotechnology on the Textile Industry

Paul Hamlyn

Biotechnology, the application of living organisms and their components to industrial products and processes, is not an industry in itself, but an important technology that will impact on many industrial sectors — including textiles, where progress to date and some future trends are assessed.

Of course, biotechnology is not new; traditional products include bread, beer, cheese, wine, and yoghurt. In textile processing the enzymatic removal of starch sizes from woven fabrics has been in use for most of this century and the fermentation vat is probably the oldest known dyeing process. What has given biotechnology a new impetus in the last few years has been the very rapid development in genetic manipulation technique (genetic engineering) which introduces the possibility of 'tailoring' organisms in order to optimise 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 is a truly interdisciplinary subject involving the integration of natural and engineering sciences.

In this article I will attempt to outline current developments and highlight those areas where biotechnology might be expected to play an increasingly important role in the textile industry worldwide.

Fibres and biopolymers

Nature has provided us with textile fibres such as cotton, wool and silk but there is now the potential to harness biotechnology and produce new or modified fibres as well as improving the production yields of existing ones. Cotton is still the world's leading textile fibre with some 20 M tons grown every year by about 80 producing countries. However, cotton has the unfortunate characteristic of being vulnerable to many insects, and to maintain yields, these insects are managed with large amounts of pesticides. Cotton is also prone to

Pilot scale bioreactor used for growing micro-organisms. *BTTG.*

Left: **Cotton: a prime candidate for improvement by biotechnology.**

infestation by weeds which thrive under the intense irrigation conditions that cotton needs throughout its growth cycle and cotton has poor tolerance to any of the herbicides in use today. It is not surprising, therefore, that biotechnology companies have focused their short term objectives on genetically engineering insect, disease and herbicide resistance into the cotton plant. Longer term goals include the modification of fibre quality and properties (e.g. length and strength) leading to the development of high performance cottons. There is already a small market for naturally coloured cottons, but the colour range that has been developed using classical selection techniques is limited. The development of transgenic intensely coloured cottons (e.g. blues and vivid reds) could one day replace the need for bleaches and dyes.

In animal breeding and health care, biotechnology is expected to have a large impact on animal fibre production over the next few years. A whole range of new technologies are now available including in vitro fertilisation and embryo transfer, diagnostics, genetically engineered vaccines and therapeutic drugs. Work currently being carried out at CSIRO, Australia's national research organisation, includes genetic modification of sheep to resist attack from blowfly larvae by engineering a sheep that secretes an insect repellent from its hair follicles and 'biological wool shearing'. The latter technique relies on an artificial epidermal growth factor which, when injected into sheep, interrupts hair growth. A month later, breaks appear in the wool fibre and the fleece can be pulled off whole in half the time it takes to shear a sheep. There is also considerable research being carried out in several countries with the aim of producing finer and therefore more valuable wools.

Novel fibre-forming biopolymers are now being manufactured using large-scale fermentation equipment. For example, the bacterial storage compound polyhydroxybutyrate (PHB) has been developed by Zeneca Bioproducts (formerly ICI Agricultural Division) and is produced under the tradename Biopol. This high molecular weight linear polyester has good thermoplastic properties (melting point 180°C) and can be melt spun into fibres. Biocompatibility and biodegradability makes PHB fibres ideally suited for surgical use; sutures made from PHB are slowly degraded by the body's enzymes. Zeneca is currently using Biopol in conventional plastics applications such as shampoo bottles. The price of the polymer is still considered too high for many fibre applications and ultimately Biopol might be produced by plants. Zeneca are experimenting with a genetically engineered variety of rape which can synthesise Biopol.

Other biopolymers currently of particular interest in wound-healing applications include the polysaccharides chitin, alginate, dextran and hyaluronic acid. Chitin and its derivative chitosan are important components of fungal cell walls, although these polymers are at present manufactured from sea food (shellfish) wastes. Patents taken out by the Japanese company Unitika cite the use of fibres made out of chitin in wound dressings. At the British Textile Technology Group, BTTG, research has been directed towards the use of intact fungal filaments as a direct source of chitin or chitosan fibre to produce inexpensive wound dressings and other novel materials. Tests carried out at the Welsh School of Pharmacy indicate that these products have wound healing acceleration properties. Wound

Major applications of biotechnology in the textile industry

- Improvement of plant varieties used in the production of textile fibres and in fibre properties
- Improvement of fibres derived from animals and health care of the animals
- Novel fibres from biopolymers and genetically modified micro-organisms
- Replacement of harsh and energy-demanding chemical treatments by enzymes in textile processing
- Environmentally friendly routes to textile auxiliaries such as dyestuffs
- Novel uses for enzymes in textile finishing
- Development of low energy enzyme based detergents
- New diagnostic tools for detection of adulteration and quality control of textiles
- Waste management

dressings based on calcium alginate fibres have already been developed by Courtaulds and are marketed under the tradename Sorbsan. Present supplies of this polysaccharide rely on its extraction from brown seaweeds. However, a polymer of similar structure can also be produced by fermentation from bacteria. Dextran, which is manufactured by the fermentation of sucrose by Leuconostoc mesenteroides or related species of bacteria, is also being developed as a fibrous non-woven for speciality end-uses such as wound dressings. Additional biopolymers, not previously available on a large scale, are now coming onto the market thanks to biotechnology. One such example is hyaluronic acid, a polydisaccharide of D-glucuronic acid and N-acetyl glucosamine, found in the connective tissue matrices of vertebrates and also present in the capsules of some bacteria. The original method of production by extraction from rooster combs was very inefficient requiring 5 kg of rooster combs to provide 4 g of hyaluronic acid. Fermentech, a British biotechnology company, is now producing hyaluronic acid by fermentation. The same amount of high quality purified hyaluronic acid can be obtained from 4 litres of fermentation broth, as opposed to 5 kg of rooster combs.

Two different biotechnological routes for the production of cellulose are under investigation in various laboratories throughout the world. Cellulose is produced as an extracellular polysaccharide by a number of different bacteria in the form of ribbon-like microfibrils. These can be used to produce moulded materials of relatively high strength. Sony, the Japanese electronics company, has patented a way of making hi-fi loudspeaker cones and diaphragms from bacterial cellulose. An alternative route to cellulose, still at a very early stage of development, concerns the in vitro cultivation of plant cells. It has already been demonstrated that cotton fibres can be produced in vitro by culturing cells of various strains of Gossypium. The potential advantages of this route include a more uniform product displaying particularly desirable properties. Plant tissue culture can provide a steady, all-year supply of products without climatic or geographic limitations and free of contamination from pests.

Proteins are another group of biopolymers of particular interest to biotechnologists because of the scope for utilising the new genetic manipulation techniques. Thus genes for animal and plant proteins (e.g. collagen, various silks) can now be transferred into suitable microbial hosts and the proteins produced by fermentation. The US Army is keen to develop spider silk as a high performance fibre for use in products such as bullet proof vests.

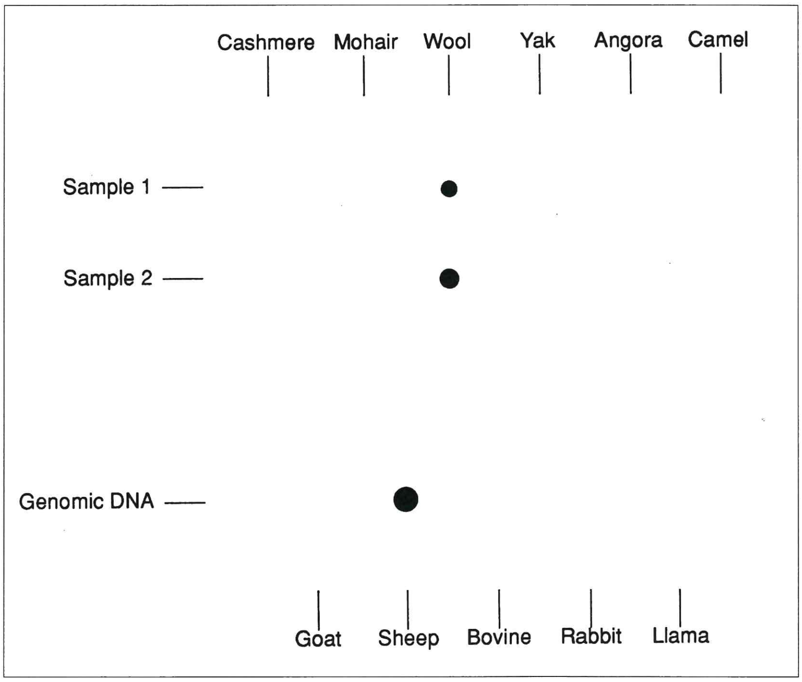
Enzymes

The mediation of chemical reactions by catalytic proteins (enzymes) is a central feature of living systems. Living cells make enzymes although the enzymes themselves are not alive. We can encourage living cells to make more enzymes than they would normally make or to make a slightly different type of enzyme (protein engineering) with improved characteristics of specificity, stability and performance in industrial processes. These enzymes usually operate under mild conditions of pH and temperature: many exhibit great

Enzymes used in detergents

Enzyme	Action
Protease	Remove stains caused by proteins such as blood, grass, egg and human sweat
Amylase	Remove starch-based stains such as those made by potatoes, pasta, rice and custard
Lipase	Break down fats, oils and greases removing stains based on salad oils, butter, fat-based sauces and soups, and certain cosmetics, such as lipstick
Cellulase	Brighten and soften the fabric, and release particles of dirt trapped in the fibres

Below: Spot test for the presence of wool DNA using a sheep-specific DNA probe. *BTTG.*



specificity and stereoselectivity.

With the notable exception of starch-size removal by amylases, however, scant attention has been given to the application of enzymes in textile processing. The preparation of certain textile fibres such as flax and hemp by dew-retting involves the action of pectolytic enzymes from various micro-organisms which degrade pectin in the middle lamella of these plant fibres. To date, no attempts appear to have been made to use isolated enzyme preparations to produce the desired effects although their effectiveness has been demonstrated in the laboratory. The use of isolated enzymes to remove fats and waxes, pectins, seed-coat material and coloured impurities from loomstate cotton and cotton/polyester fabrics, leading to a novel, low-energy fabric-preparation process, (i.e. to replace scouring and bleaching) has been investigated at BTTG. 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. One enzyme that is already being applied in textile processing for the removal of hydrogen peroxide prior to dyeing is catalase. Undoubtedly, the use of microbial enzymes can be expected to expand into many other areas of the textile industry, replacing existing chemical or mechanical processes, in the not too distant future.

In contrast to textile processing, there has been a dramatic increase in the use of enzymes in detergents since their introduction in the 1960s. Washing powders are referred to as 'biological' because they contain enzymes. Enzymes are now available that can degrade a wide range of stains and their use allows milder washing conditions at lower temperatures, which both saves energy and protects the fabric. Recently, it was discovered that cellulase enzymes could replace the pumice stones used by industry to produce 'stone-washed' denim garments. The stones can damage the clothes, particularly the hems and waistbands, and most manufacturers are now using the enzyme treatment. Another novel application for cellulase enzymes is in biopolishing, the removal of fuzz from the surface of cellulosic fibres, which eliminates pilling, making the fabrics smoother and cleaner-looking. A similar process using protease enzymes has been developed for wool.

More futuristic applications for enzymes are in the field of biotransformation. A biotransformation is defined as the biocatalytic transformation of one chemical to another. In practice, either intact cells, an extract from such cells, or an isolated enzyme may be used as the catalyst system of a specific reaction. Although the concentration of individual enzymes in cells is typically less than 1% this can now be increased using gene amplification techniques. It is not expected that the current production of bulk chemicals by oil-based processes will be replaced by biotransformations, at least in the foreseeable future. However, there are areas where biotechnology can be expected to compete with chemical synthesis. For example, the requirement for optical activity of chemicals, such as polymer precursors, is likely to grow and here the biotransformation route has a particular edge over traditional chemical methods.

Textile auxiliaries

Before the invention of synthetic dyes in the nineteenth century, many of the colours used to dye textiles came from plants, e.g. woad, indigo and madder. In the future, textile auxiliaries such as dyes may be produced by fermentation, or again from plants. Many micro-organisms produce pigments during their growth which are substantive, as indicated by the permanent staining that is often associated with mildew growth on textiles and plastics. It is not unusual for some species to produce up to 30%

Glossary

Biotechnology: the use of living organisms or their cellular, subcellular or molecular constituents to manufacture products and establish processes.

DNA: deoxyribonucleic acid. The chemical molecule that carries the hereditary information which is passed from parent to offspring.

DNA Probe: single DNA strand used to detect the presence of complementary strands of DNA.

Enzymes: protein molecules that speed-up specific chemical reactions and are unchanged by them.

Gene: unit of heredity composed of DNA.

Genetic engineering: a range of techniques for manipulating DNA and thereby modify the genetic structure of living organisms.

Transgenesis: stable incorporation of foreign DNA from one species into another. For example, insect resistant transgenic plants have been developed by incorporating genes from a bacterium.

of their dry weight as pigment. Several of these microbial pigments have been shown to be benzoquinone, naphthoquinone, anthraquinone, perinaphthenone and benzofluoranthenequinone derivatives, resembling in some instances the important group of vat dyes. Micro-organisms would therefore seem to offer great potential for the direct production of novel textile dyes or dye intermediates by controlled fermentation techniques replacing chemical synthesis, which has inherent waste disposal problems (e.g. toxic heavy-metal compounds). The production and evaluation of microbial pigments as textile colorants is currently being investigated at BTTG.

Another biotechnological route for producing pigments for use in the food, cosmetics or textile industries is from plant cell culture. One of the major success stories of plant biotechnology so far has been the commercial production, since 1983 in Japan, of the red pigment shikonin which has been incorporated into a new range of cosmetics. Traditionally, shikonin was extracted from the roots of five-year old plants of the species Lithosperum erythrorhiz where it makes up about 1-2% of the dry weight of the roots. In tissue culture, pigment yields of about 15% of the dry weight of the root cells have been achieved.

New analytical tools

Research in biotechnology has already resulted in new analytical methods for the textile industry. Work on molecular biology at BTTG has led to the development of species-specific DNA probes for animal fibres. These probes can be used to detect adulteration of high-value speciality fibres such as cashmere by much cheaper fibres (e.g. wool and yak hair). Rapid methods have been developed to assist in the early detection of biodeterioration of textile and other materials. Studies carried out at BTTG have shown that the presence of viable micro-organisms on textiles can be assessed using the enzyme luciferase isolated from the firefly (Photinus pyralis) which releases light (bioluminescence) in combination with adenosine triphosphate produced by the micro-organisms.

Waste management

Biotechnology can be used in new production processes that are less polluting than traditional ones and microbes or their enzymes are already being used to degrade toxic wastes. Waste treatment is probably the biggest industrial application of biotechnology. Specific problems pertaining to the textile industry include colour removal from dyehouse effluent, toxic heavy-metal compounds, and pentachlorophenol. The latter is used without regulation in some countries, as a rot-proofing treatment for cotton fabrics, but is washed out during subsequent processing, which may be after export to a country with strict limits on discharge. Currently much research is being carried out to resolve these problems and biotechnology would appear to offer the most effective solutions.

Conclusions

The progress now being made in biotechnology and the current level of investment by governments and individual companies has enormous commercial implications for many sectors of industry in the years ahead. Biotechnology has already developed new products, opened new markets, speeded-up production and helped to clean the environment. According to PA Consulting Group's recent study for the UK Department of Trade and Industry (DTI), many UK companies are potentially missing real business opportunities through being unaware of, or reticent about, biotechnology. The textile industry was identified as a key sector where opportunities available from adapting biotechnology are high but current awareness of biotechnology is low. Michael Heseltine recently launched the 'Biotechnology Means Business' initiative in the UK to inform companies about biotechnology and put them in touch with experts who can help them deploy biotechnology to give a competitive edge to their business and win new markets.

In this article I have not yet considered the potential applications of conventionally produced textile materials in biotechnological processes. For example, downstream processing after fermentation accounts for at least 70% of production costs in biotechnology and there is the need for improved filtration and separation techniques. Hollow fibres and membranes which separate molecules according to size are finding increased application in this area. ■

Further reading

DTI Biotechnology Unit. *Biotechnology Means Business: state of the art report on The Textile & Clothing Industries.* Teddington, LGC, 1995.

Little Book on Enzymes and the Environment. Bagsvaerd, NovoNordisk A/S, 1993.

Paul Hamlyn, MIBiol, PhD, CBiol, joined the British Textile Technology Group (then Shirley Institute) in 1982, following three years postgraduate research work at the University of Nottingham on the genetics and physiology of fungi. He previously worked in the pharmaceutical industry as a microbiologist. Section head of molecular biology and fermentation, his current research projects at BTTG are concerned with applications of biotechnology in the textile industry.