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Review

The role of biotechnology in the socio-economic advancement and national development: An Overview

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Biotechnology is any technique which involves the application of biological organisms or their components, systems or processes to manufacturing and service industries to make or modify products, to improve plants or animals or to develop micro-organisms for special uses. Since 1953, when James Watson and Francis Crick identified the structure of deoxyribonucleic acid (DNA) as the genetic basis of all living organisms, the scientific understanding of biological and genetic processes has dramatically accelerated. The present molecular techniques such as cloning, genetic engineering, recombinant DNA technique and polymerase chain reaction (PCR) involve genetic manipulations using microorganisms such as bacteriophages and bacterial plasmids as vectors and bacterial cells as hosts. Biotechnology revolution has spawned new industries focused on manipulating human, animal, plant and microbial agents to create heretofore unattainable products and services. Biotechnology occupies a very strategic position in the socio-economic advancement and development of the nation in particular and the world at large.

Key words: Biotechnology, fermentation, food, gene technology, manipulation, microbes.

BACKGROUND

Biotechnology is any technique which involves the application of biological organisms or their components, systems or processes to manufacturing and service industries make or modify products, to improve plants or animals or to develop micro-organisms for special uses (Tietyen et al., 2000; Edema, 2004). Some people use the term biotechnology to refer to the tools of genetic engineering that have been developed since 1973 (Tietyen et al., 2000). But biology, technology, and human-directed genetic change have been a part of agriculture since the beginning of cultivated crops some 10,000 years ago. Biotechnology has, in a general sense, been used as a tool for food production since the first breeders decided to selectively plant or breed only the best kinds of corn or cows. Technology is a tool we use to achieve a goal, such as improved food quality (Tietyen et al., 2000; FAO, 2000, 2004; Edema, 2004).

Scientific advances through the years have relied on the development of new tools to improve socio-economy such as health care, agricultural production, and environmental protection. Individuals, consumers, policymakers, and scientists must ultimately decide if the benefits of biotechnology are greater than the risks associated with this new approach (Tietyen et al., 2000). The technology tools used in biology have changed rapidly since scientists moved the first specific gene from one organism to another in 1973. This new era began in 1953 when scientists James Watson and Francis Crick determined the structure of DNA (Tietyen et al., 2000; Edema, 2004). DNA is the chemical language that determines the features and characteristics of all living organisms: plants, animals, and microorganisms. Once scientists understood how DNA was put together, they could determine which parts of the DNA (genes) are

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responsible for certain traits (Tietyen et al., 2000; FAO, 2000, 2004).

Genes determine traits by controlling the production of proteins, including enzymes. Proteins and enzymes are used by all living organisms to grow, metabolize energy, and become what their genetic code dictates. Each cell of an organism contains the entire genetic code needed to create the organism. The interaction of genetic makeup and environmental factors shapes the nature of all living things. When people eat a "healthy" diet, they are controlling environmental factors that will, within the limits of their genetic makeup, decrease their risk of developing a disease (Tietyen et al., 2000).

In Europe, a vast diversity of high quality foods provide the carbohydrates, fats, proteins, minerals and vitamins needed in the everyday diet of consumers. At the heart of food production is biotechnology. One aspect of biotechnology which has been used for centuries is the selective breeding of crop plants and farm animals to produce improved food. Another is fermentation, in use for millennia to produce fermented foods like cheese, bread, beer, sauerkraut and sausages (Tietyen et al., 2000; FAO, 2000, 2004).

Gene technology includes any biotechnological technique for the controlled modification or transfer of genes from one organism to another to give a desired characteristic. The first use of gene technology two decades ago opened up the potential for many additional advances in both selective breeding and fermentation. Each specific step forward might be relatively small, but together they could add up to further improvements in the nutritional quality, appearance, flavour, convenience, cost and safety of foods which are an integral part of socio-economic advancement and national development..

This overview seeks to provide science-based information about discoveries in biotechnology as it affects mankind and is designed to help us understand and assess the risks and benefits of biotechnology. It also provides information about biotechnology with examples of how these new tools of biology and agriculture are used in food production as part of socio-economic advancement and national development. It includes a perspective showing how biotechnology fits into the history and future of science and food for mankind. Its purpose is to educate people about biotechnology and its role in the socio-economic advancement and development of a nation so that they can make informed choices.

Biotechnology applications in food processing

Biotechnology includes a wide range of diverse technologies and they may be applied in each of the different food and agriculture sectors. It includes technologies such as gene modification (manipulation) and transfer, the use of molecular markers, development of recombinant vaccines and DNA-based methods of disease characterization/diagnosis, *in vitro* vegetative propagation of plants, embryo transfer and other reproductive technologies in animals or triploidization in fish. It also includes a range of technologies used to process the raw food materials produced by the crop, fishery and livestock sectors. This is the area that has received relatively little attention from the media, but which is very important for food security in many developing countries. Biotechnology in the food processing sector targets the selection and improvement of microorganisms with the objectives of improving process control, yields and efficiency as well as the quality, safety and consistency of bioprocessed products. Microorganisms or microbes are generic terms for the group of living organisms which are microscopic in size, and include bacteria, yeasts and moulds (Edema, 2004).

Fermentation is the process of bioconversion of organic substances by microorganisms and/or enzymes (complex proteins) of microbial, plant or animal origin. It is one of the oldest forms of food preservation which is applied globally. Indigenous fermented foods such as bread, cheese and wine, have been prepared and consumed for thousands of years and are strongly linked to culture and tradition, especially in rural households and village communities (Achinewu et al., 1991, 1992). It is estimated that fermented foods contribute to about one-third of the diet worldwide (FAO, 2004). During fermentation processes, microbial growth and metabolism (the biochemical processes whereby complex substances and food are broken down into simple substances) result in the production of a diversity of metabolites (products of the metabolism of these complex substances) (Omafuvbe, 1999; Omafuvbe et al., 2002). These metabolites include enzymes which are capable of breaking down carbohydrates, proteins and lipids present within the substrate and/or fermentation medium; vitamins; antimicrobial compounds (e.g. bacteriocins and lysozyme), texture-forming agents (e.g. xanthan gum), amino acids, glutamic acids (Ogbadu et al., 1990), organic acids (e.g. citric acid, lactic acid) and flavour compounds (e.g. esters and aldehydes). Many of these microbial metabolites (e.g. flavour compounds, amino acids, organic acids, enzymes, xanthan gums, alcohol, etc.) are produced at the industrial level in both developed and developing countries for use in food processing applications. A considerable volume of current research both in academia and industry targets the application of microbial biotechnology to improve the production, quality and yields of these metabolites.

Some researches have been carried out on the production of fermented condiments, iru from African locust bean (Eka, 1980; Odunfa, 1986), melon seed fermented ogiri (Odunfa, 1981; Barber and Achinewu, 1992) and soybean produced daddawa (Omafuvbe et al., 2000, 2002). Some of the most important food condiments are ogiri, which is produced from melon seeds (*Citrullus vulgaris)*, iru or dawadawa produced from locust bean (*Parkia biglobosa)* Odunfa, (1981b), ugba produced from oil bean seeds (*Pentaclethra macrophylla*) (Obeta, 1983; Odunfa and Oyeyiola, 1985), ogiri-Igbo is produced from castor oil seeds (*Ricinus*

communis) Odunfa (1985b) Dawadawa from soya-beans (Ogbadu and Okagbue, 1988). Iru from Locust beans (Odunfa, 1981a) Owoh from cotton seeds (*Gossypium hirsutum*), Okpehe from mesquite (*Prosopis africana*) (Ogunshe, 1989), Ogiri which is made from (*Parkia filicoidea)*, Melon seeds (*Citrullus vulgaris)* is also produced from Africa oil bean (*Pentaclethra macrophylla*) and Aisa from oil seeds (*Albizia saman*) (Ogunshe *et al*, 2006) are generally proceesed to yield condiments (Table 1)**.** These Africa fermented condiments requires food processing technologies that will meet the requirement/challenges of human needs. Although, fermentation rightly meets these needs of mankind. Fermentation improves markedly the digestion, nutritive value, and flavour of the raw materials used (Ogunshe, 1989).

Food condiments in Nigeria and many other countries of West and Central Africa are popular strong-smelling fermented food culinary products that give pleasant aroma to soups, sauces and other prepared dishes. They also have great potential as key protein (Umoh and Oke, 1974), fatty acid are good sources of gross energy. Therefore, condiments are basic ingredients for food supplementation and their socio-economic importance cannot be over emphasized in many countries especially in Africa and Asia (India) where protein calorie malnutrition is a major problem (Ogunshe et al., 2006). Fermented foods have a long history in Africa. However, the absence of writing culture in most African countries makes their origin difficult to trace. Perhaps the most documented of the fermented food is sour-milk, followed in historical importance by various alcohol drinks which played important part on various solemn occasions and over thirty different fermented foods have been recorded (Ogunshe, 1989).

Fermentation is globally applied in the preservation of a range of raw agricultural materials (cereals, roots, tubers, fruit and vegetables, milk, meat, fish etc.). Commercially produced fermented foods which are marketed globally include dairy products (cheese, yogurt, and fermented milks), sausages and soy sauce. Certain microorganisms associated with fermented foods, in particular are strains of the *Lactobacillus* species, which are probiotics i.e. used as live microbial dietary supplements or food ingredients that have a beneficial effect on the host by influencing the composition and/or metabolic activity of the flora of the gastrointestinal tract. Probiotic bacterial strains are also produced and commercially marketed in many developed countries. In developing countries, fermented foods are produced primarily at the household and village level, where they find wide consumer acceptance.

Food fermentations contribute substantially to food safety and food security, particularly in the rural areas of many developing countries (FAO, 2004). Traditional Fermentation processes used in the production of these foods are uncontrolled and are dependent on microorganisms from the environment or the fermentation substrate for initiation of the fermentation processes. Such processes, therefore, result in products of low yield and variable quality. Microorganisms and metabolic pathways associated with the production of fermented foods are the subject of considerable research, targeting strain isolation and identification; improvement of the efficiency of fermentation processes and the quality, safety and consistency of fermented foods (Tietyen et al., 2000; FAO, 2004). Much of this research incorporates the use of genetic technologies for strain development and improvement, and for diagnostic studies (Tietyen et al. 2000; FAO, 2004).

While microorganisms are beneficial in most fermentation processes, some may pose the risk of food contamination and can cause food-borne illness. Diagnostic methodologies which integrate the use of molecular genetic techniques enhance the speed and sensitivity of microbial testing and are increasingly being applied in developing countries (FAO, 2000, 2004). The application of biotechnology to the processing of food (including beverages) produced from agriculture involves biotechnological tools and options that are applicable to the study and improvement of microorganisms which offer potential for improving the quality, safety and consistency of fermented foods; improving efficiency in the production of fermented foods, food ingredients, food additives and food processing aids (enzymes);

Table 1. Microbial fermentation is essential to the production of these fermented Foods

	Fermented food	S/no	Fermented food
1	Aisa	17	Kefir
2	Beer	18	Miso
3	Bologna	19	Pap
4	buttermilk	20	Pickles
5	Cheeses	21	Salami
6	Cider	22	Sauerkraut
7	Cocoa	23	Sour cream
8	Coffee	24	Soy sauce
9	Cottage cheese	25	Tamari
10	Distilled liquors	26	Tea
11	Dawadawa/daddawa	27	Tempeh
12	Iru	28	Tofu
13	Ogiri	29	Ugba
14	Okpehe	30	Vinegar
15	Olives	31	Wine
16	Owoh	32	Yogurt

diversifying the outputs of fermentation processes and, finally, improving diagnostic and identification systems applicable to foods (Tietyen et al., 2000; FAO, 2004).

ADVANCES IN PECIFIC AREAS OF FOOD PROCESSING

Improved food ingredients

Necessary changes to the key food ingredients, starches and oils, are usually made by processing. Biotechnology opens up the possibility of altering crop plants to produce exactly the type of ingredients needed:

Starches

Plant breeders have introduced a bacterial gene into potato plants which increases the proportion of starch in the tubers whilst reducing their water content. This means that the potatoes absorb less fat during frying, giving low-fat chips. Sweeter potatoes have also been produced which have higher sucrose content than traditional varieties.

Oils

Both rapeseed and sunflower are being altered to produce more stable and nutritious oils, which contain linoleic acid instead of linolenic acid and have lower saturated fat content. Rapeseed has also been modified to produce a high-temperature frying oil low in saturated fat (Henkel,1995; Betsch, 1998; Tietyen et al., 2000; Peterson, 2000; Lemaux, 2000; IFIC, 2000; Biotech, 2000; Bessin et al., 2000; ADA, 2000).

Product quality

Biotechnology has been employed to change the characteristics of the raw material inputs so that they are more attractive to consumers and more amendable to processing (Biotech, 2000). Biotechnology researchers are increasing the shelf life of fresh fruits and vegetables; improving the crispness of carrots, peppers and celery; creating seedless varieties of grapes and melons; extending the seasonal geographic availability of tomatoes, strawberries and raspberries; improving the flavor of tomatoes, lettuce, peppers, peas and potatoes; and creating caffeine-free coffee and tea. Japanese scientists have now identified the enzyme that produces the chemical that makes us cry when we slice an onion. Knowing the identity of the enzyme is the first step in finding a way to block the gene to create "tearless" onions (Tietyen et al., 2000).

Much of the work on improving how well crops endure food processing involves changing the ratio of water to starch. Potatoes with higher starch content are healthier because they absorb less oil when they are fried, for example. Another important benefit is that starchier pota-

toes require less energy to process and therefore cost less to handle. Many tomato processors now use tomatoes derived from a biotechnology technique, somaclonal variant selection. The new tomatoes, used in soup, ketchup and tomato paste, contain 30 percent less water and are processed with greater efficiency. A 1.2% increase in the solid content is worth $35 million to the U.S. processed-tomato industry (Tietyen et al., 2000).

Another food processing sector that will benefit economically from better quality raw materials is the dairy products industry. Scientists in New Zealand have now used biotechnology to increase the amount of the protein casein, which is essential to cheese making, in milk by 13 percent (Betsch, 1998; ADA, 2000).

Better raw materials

In improving raw food materials, many plant breeding programmes have been directed towards boosting yield or allowing more environmentally compatible agriculture by increasing the resistance of crops to viruses, pests or herbicides. Increasing yield has clear benefits in helping to feed the world's ever-increasing population and could provide cheaper food. Plants which are resistant to attack by insect pests and diseases would need fewer pesticide applications; resistant crops such as maize, tomatoes and potatoes are already being developed (Peterson, 2000). Crops have also been produced with tolerance to modern, more environmentally compatible herbicides, with the aim of achieving optimal weed control with reduced levels of herbicide (Tietyen et al., 2000). Today, there is increasing interest in improving the nutritional value, flavour and texture of raw materials. This could help encourage greater fruit and vegetable consumption in line with government guidelines on healthy nutrition (IFIC, 2000; Biotech, 2000; ADA, 2000).

Safety of the raw materials

The most significant food-safety issue food producers' face is microbial contamination, which can occur at any point from farm to table. Any biotechnology product that decreases microbes found on animal products and crop plants will significantly improve the safety of raw materials entering the food supply. Improved food safety through decreased microbial contamination begins on the farm. Transgenic disease-resistant and insect-resistant crops have less microbial contamination (Peterson, 2000; Biotech, 2000; Bessin et al., 2000; ADA, 2000). New biotechnology diagnostics detect microbial diseases earlier and more accurately, so farmers can identify and remove diseased plants and animals before others become contaminated (Tietyen et al., 2000).

Biotechnology is improving the safety of raw materials by helping food scientists discover the exact identity of

strains of this bacterium and other important fermentors resistant to viral infection (BREI, 2006). It has been known for years that some bacteria used in food fermentation produce compounds that kill other

the allergenic protein in foods such as peanuts, soybeans and milk, so they can then remove them. Although 95 percent of food allergies can be traced to a group of eight foods, in most cases we do not know which of the thousands of proteins in a food triggered the reaction. With biotechnology techniques, great progress are been made in identifying these allergens. More importantly, scientists have succeeded in using biotechnology to block or remove allergenicity genes in peanuts, soybeans and shrimp (Tietyen et al., 2000; Lemaux, 2000; IFIC, 2000). Finally, biotechnology is helping us improve the safety of raw agricultural products by decreasing the amount of natural plant toxins found in foods such as potato and cassava (Tietyen et al., 2000)

Enhanced food safety

In addition to the many ways biotechnology is helping us enhance the safety of the food supply; biotechnology is providing us with many tools to detect microorganisms and the toxins they produce. Monoclonal antibody tests, biosensors, polymerase chain reaction (PCR) methods and DNA probes are being developed and will be used to determine the presence of harmful bacteria that cause food poisoning and food spoilage, such as *Listeria* and *Clostridium botulinum* (BREI, 2006). In addition, *E. coli* 0157:H7, the strain of *E. coli* responsible for several deaths in recent years, can now be distinguished from the many other harmless *E. coli* strains. These tests are portable, quicker and more sensitive to low levels of microbial contamination than previous tests because of the increased specificity of molecular technique. For example, the new diagnostic tests for *Salmonella* yield results in 36 h compared with the three or four days the older detection methods required. Biotechnology-based diagnostics have also been developed that they allow us to detect toxins, such as aflatoxin, produced by fungi and molds that grow on crops, and to determine whether food products have inadvertently been contaminated with peanuts, a potent allergen (BREI, 2006).

Improving food fermentors

Because of the importance of fermented foods to so many cultures, scientists are conducting a lot of work to improve the microorganisms that carry out food fermentations. The bacterium responsible for many of our fermented dairy products, such as cheese and yogurt, is susceptible to infection by a virus that causes substantial economic losses to the food industry. Through recombinant technology, researchers have made some

contaminating bacteria, which cause food poisoning and food spoilage. Using biotechnology we are equipping many of our microbial fermentors with this self-defense mechanism to decrease microbial contamination of fermented foods (BREI, 2006).

ADVANCES IN PROCESSING AIDS AND ADDITIVES

Microorganisms have been essential to the food industry not only for their importance as fermentors, but also because they are the source of many of the additives and processing aids used in food processing. Biotechnology advances will enhance their value to the food industry even further. Food additives are substances used to increase nutritional value, retard spoilage, change consistency and enhance flavor (Odunfa, 1985). The compounds food processors use as food additives are substances nature has provided and are usually of plant or microbial origin, such as xanthan gum and guar gum, which are produced by microbes. Many of the amino acid supplements, flavors, flavor enhancers and vitamins added to breakfast cereals are produced by microbial fermentation. Through biotechnology, food processors will be able to produce many compounds that could serve as food additives but that now are in scanty supply or that are found in microorganisms or plants difficult to maintain in fermentation systems. Food processors use plant starch as a thickener and fat substitute in low-fat products. Currently, the starch is extracted from plants and modified using chemicals or energy-consuming mechanical processes. Scientists are using biotechnology to change the starch in crop plants so that it no longer requires special handling before it can be used (BREI, 2006).

Traditional biotechnology has played a major role in producing fermented foods-where desirable changes are produced by the action of micro-organisms or enzymes; of which over 3,500 different types exist around the world. In Europe and North America, bread, yoghurt and cheese are perhaps most familiar. In Africa, foods made from fermented starch crops like yams and cassava are more important, whereas in Asia, products derived from fermented soya beans or fish predominate.

Fermentation can make the food more nutritious, tastier or easier to digest, and it can enhance food safety. It also helps to preserve food and to increase its shelf-life, reducing the need for additives. Genetically improved strains of microbes can make a major contribution to these desirable properties. For many years, a wide range of additives, processing aids and supplements have been obtained from microbial sources by fermentation. Products from modern biotechnology include vitamins, citric acid, natural colourings, flavourings, gums and enzymes. Gums used as low-calorie thickening agents and low-calorie sweeteners from natural ingredients are also produced using modern biotechnology. Enzymes, the naturally-occurring catalysts responsible for literally all the biochemical processes of life, are used in applications such as bakery and cheese making to improve texture, appearance and nutritional value, and to generate desirable flavours and aromas (BREI, 2006).

A second area where biotechnology has advantages is in improving the processes by which food is produced. Now, it can be used to develop mild, highly specific processes using modified micro-organisms and purer, cheaper enzyme products. These can offer better productivity, cost-effectiveness and energy efficiency than existing processes. They can produce top-quality foods with a reduced need for additives such as flavourings, and can also reduce the environmental impact of food processing.

Finally, this overview covers applications of biotechnology to processing of food as well as processing of non-food agricultural products (e.g. timber) and applying biotechnology to microorganisms for environmental purposes (bioremediation, biofuels etc.). Researches are underway at present, aiming to allow the production of better food raw materials by crop plants. However, some processing steps remain essential to bridge the gap between currently-available raw materials and the desired end-product.

CURRENT STATUS OF BIOTECHNOLOGY IN FOOD PROCESSING

Microorganisms are an integral part of the processing system during the production of fermented foods. Microbial cultures can be genetically improved using both traditional and molecular approaches, and improvement of bacteria, yeasts and moulds is the subject of much academic and industrial research. Traits which have been considered for commercial food applications in both developed and developing countries include sensory quality (flavour, aroma, visual appearance, texture and consistency), virus (bacteriophage) resistance in the case of dairy fermentations, and the ability to produce antimicrobial compounds (e.g. bacteriocins, hydrogen peroxide) for the inhibition of undesirable microorganisms. In many developing countries, the focus is on the degradation or inactivation of natural toxins (e.g. cyanogenic glucosides in cassava), mycotoxins (in cereal fermentations) and anti-nutritional factors (e.g. phytates) (FAO, 2000, 2004; BREI, 2006).

Traditional approaches

Traditional methods of genetic improvement such as classical mutagenesis and conjugation have been the basis of industrial starter culture development in bacteria (a culture used to start a food fermentation is known as a starter culture), while hybridisation has been used in the improvement of yeast strains which are widely applied industrially in baking and brewing applications (FAO, 2000, 2004).

Classical mutagenesis

This involves the production of mutants by the exposure of microbial strains to mutagenic chemicals or ultraviolet rays to induce changes in their genomes (FAO, 2004). Improved strains thus produced are selected on the basis of specific properties such as improved flavour-producing ability or resistance to bacterial viruses. Such mutants may, however, show undesirable secondary mutations which can influence the behaviour of cultures during fermentation.

Conjugation

This is a natural process whereby genetic material is transferred among closely related microbial species as a result of physical contact between the donor and the recipient microorganism. Conjugational gene exchange allows both plasmid-localised and chromosomal gene transfer (a plasmid is a circular self-replicating non-chromosomal DNA molecule found in many bacteria, capable of transfer between bacterial cells of the same species, and occasionally of different species) (FAO, 2004).

Hybridization (i.e. sexual breeding or mating)

Sexual reproduction in yeasts, and thus genetic recombination, has led to improvements in yeasts. For example, crossing of haploid yeast strains with excellent gassing properties and with good drying properties could yield a novel strain with both good gassing and drying properties (FAO, 2000, 2004).

Genetic modification

Recombinant DNA approaches have been used for genetic modification of bacterial, yeast and mould strains to promote expression of desirable genes, to hinder the expression of others, to alter specific genes or to inactivate genes so as to block specific pathways (Lemaux, 2000; FAO, 2004). The successful application of genetic modification for food bio-processing applications requires the development and use of food grade vectors, i.e. plasmids which do not contain antibiotic resistant genes as markers and which consist of DNA sequences from microorganisms which are generally recognized as safe (GRAS). Genetically Modified (GM) yeasts that are appropriate for brewing and baking applications have been approved for use (e.g. approval was granted in the United Kingdom for use of a GM yeast (*Saccharomyces cerevisiae*) in beer production, containing a transferred gene from the closely related *Saccharomyces diastaticus*, allowing it to better utilise the carbohydrate present in conventional feedstocks. None of these GM yeasts are, however, used commercially (FAO, 2000, 2004).

Genetic characterization

The genetic characterization of microbial strains through the use of molecular diagnostic techniques can contribute tremendously to the understanding of fermentation processes. Molecular diagnostics provide outstanding tools for the detection, identification and characterization of microbial strains for bio-processing applications and for the improvement of fermentation processes. The application of these and other related techniques, along with the development of molecular markers for bacterial strains, greatly facilitates understanding of the ecological interactions of microbial strains, their roles, succession, competition and prevalence in food fermentations and allows the correlation of these features to desirable quality attributes of the final product (FAO, 2000, 2004).

Genomics

In recent years, the genome sequences of many food-related microorganisms have been completed (e.g. *S.cerevisiae*, commonly known as baker's or brewer's yeast, was the first eukaryote to have its genome sequenced - in 1996) and large numbers of microbial genome sequencing projects are also underway. Functional genomics, a relatively new area of research, aims to determine patterns of gene expression and interaction in the genome, based on the knowledge of extensive or complete genomic sequence of an organism. It can provide an understanding of how microorganisms respond to environmental influences at the genetic level (i.e. by expressing specific genes) in different situations or ecologies, and should therefore allow adaptation of conditions to improve technological processes. For a range of microorganisms, it is now possible to observe the expression of many genes simultaneously, even those with unknown biological functions, as they are switched on and off during normal development or while an organism attempts to cope with pathogens or changing environmental conditions.

Cooper (2003) describes the use of DNA macroarrays to analyze expression of all 4,290 genes of the model bacterium *E. coli* after 20,000 generations of evolution in a glucose-limited medium. Functional genomics can, for example, shed light on common genetic mechanisms which enable microorganisms to use certain sugars during fermentation, as well as on genetic differences allowing some strains to perform better than others. It holds great potential for defining and modifying elusive metabolic mechanisms used by microorganisms. Moving from the gene to the protein level, it should also be mentioned that proteomics, an approach aiming to identify and characterize complete sets of protein, and protein-protein interactions in a given species, is also a very active area of research which offers potential for improving fermentation technologies (FAO, 2000, 2004; BREI, 2006).

Biotechnology applications in production of food ingredients

Flavouring agents, organic acids, food additives and amino acids are all metabolites of microorganisms during fermentation processes. Microbial fermentation processes are therefore commercially exploited for production of these food ingredients. Metabolic engineering, a new approach involving the targeted and purposeful manipulation of the metabolic pathways of an organism, is being widely researched to improve the quality and yields of these food ingredients. It typically involves alteration of cellular activities by the manipulation of the enzymatic, transport and regulatory functions of the cell using recombinant DNA and other genetic techniques. Understanding the metabolic pathways associated with these fermentation processes, and the ability to redirect metabolic pathways, can increase production of these metabolites and lead to production of novel metabolites and a diversified product base (FAO, 2000, 2004).

Biotechnology applications in diagnostics/food testing

Many of the classical food microbiological methods used in the past were culture-based, with microorganisms grown on agar plates and detected through biochemical identification. These methods are often tedious, labour-intensive and slow. Genetic based diagnostic and identification systems can greatly enhance the specificity, sensitivity and speed of microbial testing. Molecular typing methodologies, commonly involving the polymerase chain reaction (PCR), ribotyping (a method to determine homologies and differences between bacteria at the species or sub-species (strain) level, using restriction fragment length polymorphism (RFLP) analysis of ribosomal ribonucleic acids (rRNA) genes) and pulsed-field gel electrophoresis (PFGE, a method of separating large DNA molecules that can be used for typing microbial strains), can be used to characterise and monitor the presence of spoilage flora (microbes causing food to become unfit for eating), normal flora and microflora in foods. Random amplified polymorphic DNA (RAPD) or amplified fragment length polymorphism (AFLP) molecular marker systems can also be used for the comparison of genetic differences between species, subspecies and strains, depending on the reaction conditions used. The use of combinations of these technologies and other genetic tests allows the characterization and identification of organisms at the genus, species, sub-species and even strain levels, thereby making it possible to pinpoint sources of food contamination, to trace microorganisms throughout the food chain or to identify the causal agents of food borne illnesses. Monoclonal and polyclonal antibodies can also be used for diagnostics, e.g. in enzyme-linked immunosorbent assay (ELISA) kits (FAO, 2000, 2004).

Microarrays are biosensors which consist of large numbers of parallel hybrid receptors (DNA, proteins, oligonucleotides). Microarrays are also referred to as biochip, DNA chip, DNA microarray or gene arrays and offer unprecedented opportunities and approaches to diagnostic and detection methods. They can be used for the detection of pathogens, pesticides and toxins and offer considerable potential for facilitating process control, the control of fermentation processes and monitoring the quality and safety of raw materials (FAO, 2000, 2004; BREI, 2006).

Biotechnology applications in the enzymes production

Enzymes are biological catalysts used to facilitate and speed up metabolic reactions in living organisms. They are proteins and require a specific substrate on which to work. Their catalyzing conditions are set within narrow limits, e.g. optimum temperature, pH conditions and oxygen concentration. Most enzymes are denatured at temperatures above 42°C. However, certain bacterial enzymes are tolerant to a broader temperature range. Enzymes are essential in the metabolism of all living organisms and are widely applied as processing aids in the food and beverage industry (FAO, 2000, 2004; BREI, 2006).

In the past, enzymes were isolated primarily from plant and animal sources, and thus a relatively limited number of enzymes were available to the food processor at a high cost. Today, bacteria and fungi are exploited and used for the commercial production of a diversity of enzymes (Table 2). Several strains of microorganisms have been selected or genetically modified to increase the efficiency with which they produce enzymes. In most cases, the modified genes are of microbial origin, although they may also come from different kingdoms. For example, the DNA coding for chymosin, an enzyme found in the stomach of calves, that causes milk to curdle during the production of cheese, has been successfully cloned into yeasts (*Kluyveromyces lactis*), bacteria (*E. coli*) and moulds (*Aspergillus niger* var. *awamori*).

Table 2. Marketed enzymes produced using gene technology.

Principal enzyme activity	**Application**
Alpha-acetolactate decarboxylase	Brewing
Alpha-amylase	Baking, brewing, distilling, starch
Catalase	Mayonnaise
Chymosin	Cheese
Beta-glucanase	Brewing
Alpha-glucanotransferase	Starch
Glucose isomerase	Starch
Glucose oxidase	Baking, egg mayonnaise
Hemicellulase	Baking
Lipase	Fats, oils
Maltogenic amylase	Baking, starch
Microbial rennet	Dairy
Phytase	Starch
Protease	Baking, brewing, diary, distilling, fish, meat, starch, vegetable
Pullulanase	Brewing, starch
Xylanase	Baking, starch

Chymosin produced by these recombinant microorganisms is currently commercially produced and is widely used in cheese manufacture (FAO, 2000, 2004).

The industrial production of enzymes from microorganisms involves culturing the microorganisms in huge tanks where enzymes are secreted into the fermentation medium as metabolites of microbial activity. Enzymes thus produced are extracted, purified and used as processing aids in the food industry and for other applications. Purified enzymes are cell free entities and do not contain any other macromolecules such as DNA. Genetic technologies have not only improved the efficiency with which enzymes can be produced, but they have increased their availability, reduced their cost and improved their quality. This has had the beneficial impact of increasing efficiency and streamlining processes which employ the use of enzymes as processing aids in the food industry.

In addition, through protein engineering, it is possible to generate novel enzymes with modified structures that confer novel desired properties, such as improved activity or thermostability or the ability to work on a new substrate or at a higher pH. Directed evolution is one of the main methods currently used for protein engineering. This technique involves creating large numbers of new enzyme variants by random genetic mutation and subsequently screening them to identify the improved variants. This process is carried out repeatedly, thus mimicking natural evolution processes (Tietyen et al., 2000; IFIC, 2000; Biotech, 2000; ADA, 2000)

Biotechnology application in environment

Biotechnology application to microorganisms for environmental purposes includes bioremediation, biofuels, etc. Bioremediation is often successful and the most inexpensive method, it is only one of many techniques for dealing with hazardous wastes. This biological treatment is desirable because it is inexpensive, can be done at the site of pollution, and causes minimal physical disturbance to the surrounding area compared to other methods. The biological treatment of the contaminated soil and water is increasingly gaining popularity and acceptance though the technological advancement involved favours the industrialized countries due to limited access to these environmental technologies by developing countries which often lack the environmental regulatory framework for the application of biological treatment (Lehmann, 1998; Aririatu et al., 1999).

Though, environmental problems are one of the most important concerns for society, especially the wastes produced by industrial activity. The fermentation processes of foods, industrial production of dyes and textile material as well as domestic activities generate effluents with a high organic load. Most of the organic matter in waste has been removed by means of conventional anaerobic and/or aerobic biodegradation treatments. The use of specific treatments, physico-chemical (McLanglin,1992; Migo et al., 1993; Filipovic-Kovacevic and Spos, 1995) or biological (Duran et al., 1994; Harada et al., 1996), or to remove the colour compounds is needed, as well as to optimize the operation conditions that are directly related to the characteristics of the treated waste (Benito et.al., 1997).

Basic biological treatment or bioremediation is preferred over and above the other methods of treatment technologies such as physical, chemical, and thermal which are fast and controllable but requires high energy and cost prohibitive (Damelle, 1995; Aririatu et al., 1999) and the techniques involved in biological treatment are usually cheap and do not need extensive training and controls and its basic principles are of universal validity.

Since the environmental issues are the same, in many areas of the world, especially the developing countries, there is a current drive for maximum and optimum utilization of all the possible byproducts from forest-based industries, of which, many new plant materials have already attracted attention (Varshney and Bhoi, 1988). According to Sutherland et al. (1994), Jahn and Hamid (1979) and Jahn (1981), the use of natural coagulants of plant origin to clarify turbid surface waters or employed in the treatment of muddy river water is not a new idea and waste minimization is a major concern of the whole concept.

Biotechnology in agriculture

Applications of biotechnology to plants or animals have improved their food processing properties (e.g. development of the Flavr Savr tomato variety, genetically modified to reduce its ripening rate) and the production of proteins from genetically modified (GM) microorganisms to improve plant or animal production (e.g. production of bovine somatotropin (BST), a hormone increasing milk production in dairy cows, by GM bacteria) (Lemaux, 2000; Tietyen et al., 2000).

Advances from plant breeders to gene jockeys

Plant breeders have for many years used tools and techniques such as selective hybridization, grafting and cell isolation to improve crop quality and yield. And these early agricultural scientists made great advances, producing juicy ears of corn instead of hard-kerneled corn, which must be ground into flour, and present-day kiwi fruits rather than the hard berry from which they were developed. Scientists using the relatively new tools of biotechnology have been called "gene jockeys" because of the great degree of speed and control with which they can change the inherited traits of plants, animals, and microorganisms. Today scientists can identify the gene(s) responsible for specific characteristics, such as disease resistance or nutrient composition, and insert them into another organism. What once took decades now takes years and can be accomplished with greater accuracy (Tietyen et al., 2000).

One of the most striking differences between traditional breeding and the genetic engineering approach is that the source of genetic material need not come from the same species. This allows scientists to exchange genetic information between bacteria, plants, and animals (including humans). These new techniques have prompted considerable debate on the ethical and moral aspects of this branch of science. All living organisms share the same genetic language. In fact, you probably share about half of your genetic information with a tomato plant. And the genetic information from that tomato plant can function in a corn plant. New techniques even allow scientists to decide in which part of the plant tissue a trait should be expressed, such as the pulp versus the skin of an apple (Tietyen et al., 2000).

When considering the risks associated with these new tools of food production, consumers need to understand how these tools differ from traditional agricultural methods. With traditional breeding methods, for example, increased levels of naturally occurring toxins may result from cross breeding designed to improve a crop. Breeders spend years "back-crossing" to rid the new plant of the undesired feature while maintaining the benefits of the hybrid. There are also risks associated with the current standard use of chemicals to allow crops to tolerate insects, infections, and adverse weather conditions (Henkel, 1995; Betsch, 1998; Tietyen et al., 2000; Peterson, 2000; 2000; IFIC, 2000; Biotech, 2000; Bessin et al., 2000; ADA, 2000; BREI, 2006).

Plant foods

When working with plant foods, scientists seek to improve foods for the benefit of consumers, producers, or the environment. Consumers may benefit from improved nutrition or food quality. Producers may be able to grow crops under adverse conditions, such as drought. Some genetically engineered plant foods require significantly fewer chemical applications during growth and therefore have less environmental impact. Scientists use their current knowledge of plant biology to help them decide how to improve plant traits for foods. In the case of the slow-ripening Flavr Savr™ tomato introduced in 1994 by Calgene Inc., which was one of the first food plants produced using the tools of biotechnology, scientists knew that a type of protein called an enzyme causes tomatoes to soften as they ripen. When they isolated the gene responsible for the softening enzyme and inserted it *backwards* into the tomato's genetic code, the resulting tomato maintained good eating quality for a longer time than regular tomatoes. This technique allows better-tasting tomatoes to be grown and shipped to distant markets (Tietyen et al., 2000).

In 1986, a herbicide-resistant soybean was created using the tools of biotechnology. After several years of tests and studies, the Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) granted approval in 1994. The Environmental Protection Agency (EPA) granted approval in 1995, and the new soybeans were grown commercially in 1996. Given the widespread use of soybean products as food ingredients, it has been estimated that most U.S. food consumers in the year 2000 have eaten foods produced through genetic engineering. In 1997, 18 crop applications were approved by the U.S. agencies responsible for regulating biotechnology. An estimated 35 percent of the 1999 U.S. corn and 55 percent of the soybean crop were grown from genetically modified seeds (Henkel, 1995; Tietyen et al., 2000; Peterson, 2000; Lemaux, 2000; Biotech, 2000; BREI, 2006)

Animal foods

The first FDA-approved application of biotechnology for production of food animals was to modify a microorganism to make a hormone needed for milk production in dairy cows. This genetically modified organism (GMO) is a bacterium that can produce large quantities of the hormone for injection into dairy cows. An estimated one-third of U.S. milk is produced using the GMO-produced hormone, which increases milk production by 10 to 25 percent. Another GMO is used to produce about 75 percent of U.S. cheese by providing a necessary enzyme formerly harvested from the stomach lining of cows (Tietyen et al., 2000). In addition to the use of GMOs in animal food production, biotechnology can be used to create transgenic animals. But developments of this biotechnology application may be slow due to the generally greater difficulties in animal genetic engineering and to the social and ethical concerns of consumers about the animal food applications of biotechnology. Nevertheless, some genetically modified food animals are under consideration for approval and marketing. An example is a salmon that grows to a marketable size more rapidly than regular salmon. Most transgenic animal research is for medical applications, as in the case of the cloned sheep "Dolly," where scientists are investigating cystic fibrosis disease (Tietyen et al., 2000; BREI, 2006).

PROMISING CROP PLANTS

Improved nutritional value

Crops in development include soybeans with higher protein content; potatoes with more nutritionally available starch and with improved amino acid content; pulses such as beans which have been altered to produce essential amino acids; crops which produce beta-carotene, a precursor of vitamin A; and crop plants with a modified fatty acid profile. An example is a strain of oilseed rape which produces a special type of polyunsaturated fatty acid (the so-called w3-fatty acids). These have been linked to brain development and have potential in a range of speciality, clinical and infant foods (Tietyen et al., 2000).

Better flavour

Different types of peppers and melons with improved flavour are currently in field trials. Flavour can also be improved by enhancing the activity of plant enzymes which transform aroma precursors into flavouring compounds (Tietyen et al., 2000).

Improved keeping properties

There is improved keeping properties with the aim of making transport of fresh produce easier, giving consumers access to nutritionally valuable whole foods and preventing decay, damage and loss of nutrients. Examples include the improved tomatoes now being sold in the US, and recently approved in the UK, which have been genetically altered to delay softening. Research is underway on making similar modifications to broccoli, celery, carrots, melon and raspberries. The shelf-life of some processed foods such as peanuts has also been improved by using raw materials with a modified fatty acid profile (Tietyen et al., 2000; BREI, 2006).

Reduced levels of toxicants

There is reduced level of toxicants thereby allowing a wider range of plants to be used as food crops, such as the edible strain of sweet lupin which has been developed through conventional breeding techniques (BREI, 2006).

BIOTECHNOLOGY ISSUES OF RELEVANCE TO DEVELOPING COUNTRIES

Biotechnological research as applied to bio-processing in the majority of developing countries, targets development and improvement of traditional fermentation processes. This aspect of the overview considers some areas specifically relevant to developing countries and some key issues that should be considered are listed.

Socio-economic and cultural factors

Traditional fermentation processes employed in most developing countries are low input, appropriate food processing technologies with minimal investment requirements. They make use of locally produced raw materials and are an integral part of village life. These processes are, however, often uncontrolled, unhygienic and inefficient and generally result in products of variable quality and short shelf lives. Fermented foods, nevertheless, find wide consumer acceptance in developing countries and contribute substantially to food security and nutrition. The question now is: How will applications of biotechnology to fermented foods impact on these socio-economic and cultural factors?

Infrastructural and logistical factors

Physical infrastructural requirements for the manufacture, distribution and storage (e.g. by refrigeration) of microbial cultures or enzymes on a continuous basis is generally available in urban areas of many developing countries. However, this is not the case in most rural areas of developing countries. The question now is: Should research be oriented to ensure that individuals at all levels can benefit from applications of biotechnology in food fermentation processes, i.e. should logistical arrangements for starter culture development be integrated into biotechnological research targeting improvement of traditional fermentations? What is required for the level of fermentation technologies and process controls to be upgraded in order to increase efficiency, yields and the quality and safety of fermented foods in developing countries?

Nutrition and food safety

Fermentation processes enhance the nutritional value of foods through the biosynthesis of vitamins, essential amino acids and proteins, through improving protein and fibre digestibility; enhancing micronutrient bioavailability and degrading anti-nutritional factors. Many bacteria in fermented foods also exhibit functional properties (probiotics). The safety of fermented food products is enhanced through reduction of toxic compounds, such as mycotoxins and cyanogenic glucosides, and production of antimicrobial factors, such as bacteriocins, carbon dioxide, hydrogen peroxide and ethanol, which facilitate inhibition or elimination of food-borne pathogens. The question now is: Are the nutritional characteristics (and safety aspects) of fermented foods adequately documented and appreciated in developing countries? Is there a need for consumer education about the benefits of fermented foods?

Intellectual property rights (IPRs)

The processes used in the more advanced areas of agricultural biotechnology tend to be covered by IPRs and these rights tend to be owned by parties in developed countries. This applies also to biotechnology processes used in food processing. On the other hand, many of the traditional fermentation processes applied in developing countries are based on traditional knowledge. In addition to biotechnology processes, microbial strains may also be the object of IPRs. For example, an era of massive private investment in biotechnology was initiated when the United States Supreme Court ruled in 1980 (in the Diamond versus Chakrabarty case) that a live GM bacterium (of the genus *Pseudomonas*, modified to degrade components of crude oil) could be patented.

Many of the microorganisms associated with traditional fermentation processes in developing countries are unique. Issues of ownership will become increasingly important as bacterial strains are characterized and starter cultures are developed in developing countries. The question now is: How should food scientists, researchers, industry and governments in developing countries approach these issues? A considerable volume of research into the development and improvement of fermentation processes is currently taking place worldwide. Are the research results from developing countries adequately documented? Who owns this information? Are cell banks being developed to protect microbial strains characterized in developing countries?

Commercial opportunities

Biotechnology also allows the economically viable production of valuable, naturally occurring compounds that cannot be manufactured by other means. For example, commercial-scale production of the natural and highly marketable sweetener known as fructans has long eluded food-processing engineers. Fructans, which are short chains of the sugar molecule fructose, taste like sugar but have no calories. Scientists found a gene that converts 90 percent of the sugar found in beets to fructans. Because 40 percent of the transgenic beet dry weight is fructans, this crop can serve as a manufacturing facility for fructans.

Biotechnological innovations have greatly assisted in industrializing production of certain indigenous fermented foods. Indonesian tempe and Oriental soy sauce are well known examples of indigenous fermented foods that have been industrialized and marketed globally. The results of biotechnology research will lead to fermented foods of improved quality, safety and consistency. The question now is: Should biotechnology developments in developing countries target commercialization? Should they target diversification into new value-added products? Should biotechnology development be linked to technological developments in food processing? Can the application of biotechnology to food processing allow farmers in developing countries to add value to their agricultural products (for export or for local consumption) and improve their revenues?

Appropriateness of biotechnology in developing countries

As with any commitment of resources, investments in biotechnology should be weighed up against other potential uses of these resources in developing countries. How relevant and worthwhile can such investments on biotechnology be for developing countries?

CONCLUSION

Biotechnology revolution has spawned new industries focused on manipulating human, animal, plant and microbial agents to create heretofore unattainable products and services such as fermented food products which have great potential as key protein, fatty acid and good sources of gross energy, therefore, condiments are basic ingredients for food supplementation and their socio-economic importance cannot be over emphasized in many countries especially in Africa and Asia (India) where protein calorie malnutrition is a major problem. Biological organisms that are being used in most biotechnological processes are microorganisms, which are very small living things which are invisible to the naked eyes but can only be seen with the aid of a microscope. They play this vital role because of the simplicity of their genome, their short generation time, ease of manipulation, their use of synthetic medium for growth among other factors. The present molecular techniques such as cloning, genetic engineering, recombinant DNA technique and polymerase chain reaction (PCR), ribotyping, using restriction fragment length polymorphism (RFLP), and pulsed-field gel electrophoresis (PFGE), Random amplified polymorphic DNA (RAPD) or amplified fragment length polymorphism (AFLP) molecular marker systems involve genetic manipulations using microorganisms such as bacteriophages and bacterial plasmids as vectors and bacterial cells as hosts. This therefore implies that biotechnology occupy a very strategic position in the socio-economic advancement and development of the nation in particular and the world at large.

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