Consortium for Educational Communication

Module

on

Biotechnology: Application In Food Industry

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TEXT

➢ Biotechnology and food industry

Food processing makes use of various unit operations and technologies to convert relatively bulky, perishable and typically inedible raw materials into more useful shelf-stable and palatable foods or potable beverages. Processing contributes to food security by minimizing waste and losses in the food chain and by increasing food availability and marketability. Food is also processed in order to improve its quality and safety. Food safety is a scientific discipline that provides assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use. Biotechnology as applied to food processing in most developing countries makes use of microbial inoculants to enhance properties such as the taste, aroma, shelf-life, texture and nutritional value of foods. The process whereby micro-organisms and their enzymes bring about these desirable changes in food materials is known as fermentation. Fermentation processing is also widely applied in the production of microbial cultures, enzymes, flavours, fragrances, food additives and a range of other high value-added products. These high value products are increasingly produced in more technologically advanced developing countries for use in their food and non-food processing applications. Many of these high value products are also imported by developing countries for use in their food-processing applications. The prospects and potential of applying biotechnology in food processing operations and to address safety issues in food systems with the objective of addressing food security and responding to changing consumer trends in developing countries. It is important to note that food safety evaluation or risk assessment will not be discussed. Instead, we are focusing on the context of biotechnologies as applied to food safety. Technologies applied in the processing of food must assure the quality and safety of the final product. Safe food is food in which physical, chemical or microbiological hazards are present at a level that does not present a public health risk. Safe food can, therefore, be consumed with the assurance that there are no serious health implications for the consumer. Recent food scares such as mad cow disease and the melamine contamination of food products have increased consumer concern for food safety. As incomes rise, consumers are increasingly willing to pay a premium for quality, safety and convenience.

A range of technologies is applied at different levels and scales of operation in food processing across the developing world. Conventional or "low-input" food processing technologies include drying, fermentation, salting, and various forms of cooking, including roasting, frying, smoking, steaming, and oven baking. Low-income economies are likely to employ these as predominant technologies for the processing of staple foods. Many of these technologies make use of a simple, often rudimentary, technological base. Medium levels of processing technologies such as canning, oven drying, spray drying, freeze drying, freezing, pasteurization, vacuum packing, osmotic dehydration and sugar crystallization are widely applied in middle- and upper middle-income economies. Higher-level, more capital-intensive food-processing technologies such as high-temperature short-time pasteurization and high-pressure low-temperature food processing are widely employed in middle- and upper middle-income economies. Functional additives and ingredients produced using fermentation processes are generally incorporated into food-processing operations that make use of higher-level technologies.

Traditional methods of food-safety monitoring such as the detection of pathogenic bacteria in food are generally based on the use of culture media. These are the techniques of choice in low- and lower-middle-income economies which lack the resources, infrastructure and technical capacity to utilize modern biotechnological techniques. Conventional bacterial detection methods are time-consuming multi-step procedures. At least two to three days are required for the initial isolation of an organism, followed by the requirement for several days of additional confirmatory testing. Biotechnology-based methods can provide accurate results within a relatively short time frame. Biotechnological developments have resulted in the widespread availability of low-cost rapid methods of identification when compared with the significant cost/time requirements of conventional techniques. Lower-middle-income economies apply both traditional and more sophisticated methods for monitoring the microbiological quality of foods and their conformance to international standards. A number of case studies are described to demonstrate the utility of biotechnology-based applications in food processing and food safety. These case studies provide the basis for the development of strategic interventions designed to upgrade food processing and food safety in developing countries through the application of biotechnology.

Biotechnology in the food processing sector makes use of micro-organisms for the preservation of food and for the production of a range of value-added products such as enzymes, flavour compounds, vitamins, microbial cultures and food ingredients. Biotechnology applications in the food-processing sector, therefore, target the selection and manipulation of micro-organisms with the objective of improving process control, product quality, safety, consistency and yield, while increasing process efficiency. Biotechnological processes applicable to the improvement of microbial cultures for use in food-processing applications include traditional methods of genetic improvement (traditional biotechnology) such as classical mutagenesis and conjugation. These methods generally focus on improving the quality of micro-organisms and the yields of metabolites. Hybridization is also used for the improvement of yeasts involved in baking, brewing and in beverage production. *Saccharomyces cerevisiae* strains have, for example, been researched for improved fermentation, processing and biopreservation abilities, and for capacities to increase the wholesomeness and sensory quality of wine . Recombinant gene technology, the best-known modern biotechnology, is widely employed in research and development for strain improvement. The availability of genetic manipulation tools and the opportunities that exist to improve the microbial cultures associated with food fermentations are tempered by concerns over regulatory issues and consumer perceptions. Genetically modified (GM) microbial cultures are, however, used in the production of enzymes and various food-processing ingredients such as monosodium glutamate, polyunsaturated fatty acids and amino acids. Biotechnology is also widely employed as a tool in diagnostics in order to monitor food safety, prevent and diagnose food-borne illnesses and verify the origins of foods. Techniques applied in the assurance of food safety focus on the detection and monitoring of hazards whether biological, chemical or physical.

➢ Current status of biotechnology in food processing

Biotechnology in food fermentation: 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).

1. 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.

a) 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. 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.

b) 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 nonchromosomal DNA molecule found in many bacteria, capable of transfer between bacterial cells of the same species, and occasionally of different species).

c) Hybridisation (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.

2. Molecular approaches

a) 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. 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 resistance genes as markers and which consist of DNA sequences from microorganisms which are generally recognised as safe (GRAS). GM yeasts 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 utilize the carbohydrate present in conventional feedstocks). None of these GM yeasts are, however, used commercially.

b) Genetic characterisation

The genetic characterisation 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 characterisation of microbial strains for bioprocessing 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.

c) Genomics

In recent years, the genome sequences of many food-related microorganisms have been completed (e.g. *Saccharomyces cerevisiae*, commonly known as baker's or brewer's yeast, was the first eucaryote 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, describes their use of DNA macroarrays

to analyse expression of all 4,290 genes of the model bacterium *Escherichia 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 characterise 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.

Biotechnology in the production of enzymes

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 catalysing 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. 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. 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 (*Escherichia coli*) and moulds (*Aspergillus niger* var. *awamori*). Chymosin produced by these recombinant microorganisms is currently commercially produced and is widely used in cheese manufacture. 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.

Biotechnology in the production of food ingredients

The 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.

Biotechnology in diagnostics for 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 characterize 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 characterisation 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 foodborne illnesses. Monoclonal and polyclonal antibodies can also be used for diagnostics, e.g. in enzymelinked

immunosorbent assay (ELISA) kits. 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.

- **Applications of biotechnology in food industry:**

The use of biotechnology in the food industry has a lot in common with the use of biotechnology in the larger domain of agriculture. A discussion on either subject tends to overlap with common features. However, in this article we intend to specifically focus on biotechnology in food industry, as it has evolved over the years. The use of biotechnology in the food industry is primarily based on the use of enzymes that are to be found in different microorganisms. This is of course nothing new. Although we seldom emphasize this fact, several food products of day to day use that have been around for hundreds of years like alcohol, beer, vinegar, cheese, bread and curd are products of biotechnology, since enzymes and microorganisms have had a role to play in their making.

Bread:

Let's evaluate a few of these food items and see how biotechnology helps in making these products even better. Take the common bread for instance. Traditionally the method has been that, when bread is made, the dough

that is used for making the bread comes in contact with yeast cells (these cells feed on the nutrients in the dough) and the process generates alcohol and carbon dioxide with the former responsible for the aroma that you could smell when bread is baked, while it is the latter that is responsible for the texture of the loaf. And all along it has been the enzymatic effect of yeast cells that kept the bread fresh up to a point. But now there are enzymes for dough strengthening and conditioning as well. It is interesting how lipases have contributed to the strengthening and stability of the dough that goes into the making of bread. Earlier chemical dough strengtheners and emulsifiers were used until the lipases came on the scene. Now these lipase enzymes itself have undergone transformation, which means even better enzymes that permit better high speed mixing of the dough and which do not contribute to the release of fatty acids that are primarily responsible for the stale flavor of bread as opposed to the aroma of the freshly baked bread. For making bread soft, bakers had been using for a long time alpha amylase enzyme. This has given way to Novamyl a proprietary enzyme which keeps the bread even fresher. Bread can be made more soft using bacterial amylases or other specialty amylases as well. The role of proteolytic enzymes in bread making is significant. Bread is made of wheat flour and gluten happens to be the building block of wheat flour. These enzymes were originally used to make the bread softer and allow better machinability of the dough. But now these proteolytic enzymes of proprietory origin have the ability to offer even better machinability (as for example reduce mixing time for instance) in addition to giving improved color and flavor to the bread There are other enzymes that prevent bread from turning stale, which means that bread gets a longer shelf life. The reason why bread gets stale is due to the crystallization of the starch (or what is called starch retrogradation) in the bread. Microbial spoilage of bread is also a possibility. There are enzymes that when used prevent this from happening, and keeps the bread spongy and fresh for longer periods. Using current enzyme technology it is now possible to extend the shelf life of bread to more than a week, although consumer acceptance is a different matter altogether. To sum up, advances in biotechnology plays a key role in the making of bread. Apart from enzymes in bread making already discussed so far, other key enzymes like transglutaminases, oxidases, and xylase have a role to play in modern day bread making. In most cases, reference to any of these enzymes means a proprietary blend of enzymes, in which the dominant enzyme in the mix contributes the name by which the enzyme product is known. This not only emphasizes the complexity of enzymes that have a role in bread making, but also helps us reckon with the transformational change the bread making industry has undergone over the years thanks to biotechnology.

In Making Beer:

Take the case of beer, and see how biotechnology has contributed to beer making process. Traditionally beer has been made from cereal grains (which contain abundant starch and sugar) by breaking them down to form alcohol using yeast. What you see at the top of the beer "the froth" is the carbon dioxide gas that the yeast cells produce so what's happening is the fermentation of sugars in starchy material. As it was made hundreds of years ago, water, hops, yeast and barley are needed for making beer. But recent biotechnological advances have altered the structure of the yeast, so for example, you can now get brewers yeast which can ferment even hitherto unfermentable carbohydrates. Earlier the process of malting (partial germination of barley for instance in making enzymes that ultimately break these hard to ferment complex sugars) was used to break these unfermentable substances. Malting is considered expensive, but now enzymes added to unmalted barley can easily convert complex polysaccharides to simple sugars that yeast can easily ferment. That apart, enzymes can help in faster maturation after fermentation, and also help in making lighter beer with less of carbohydrates. If this was not enough, thanks to biotechnology, now there are specialized strains of bacteria for imparting flavor and quality to the beer, enzymes to make the beer making process cheaper and to ensure quality in each and every bottle apart from enzymes to help in aging, and enzymes to control alcohol and sugar content. So just as in bread making, in beer making too biotechnology has played a transformational role.

Fruit and vegetable juices:

In making fruit juices too biotechnology has a role, as for example, the use of proprietary enzymes mostly pectinases helps increase the quantity of antioxidants and color in vegetable and fruit juices made by pressing and other means. Citrus fruits have some bitter compounds and that can be eliminated using certain enzymes too.

Cheese and other products:

In cheese production, advances in biotechnology have enabled the use of microbial rennet instead of rennet's of animal origin. Protease enzymes are used to assist in gaining flavor and in cheese ripening. Coffee whiteners and margarine get their dairy flavor from proprietary fungal lipases. The list is almost endless. Although the use of enzymes in making better food products offers lower costs and manufacturing advantages, the pace of development

of food products using biotechnology will greatly depend on the acceptance of the products already made using this cutting edge technology. This is not to say that bread and beer don't have wide acceptance. But there are food products from the agricultural sector that don't have a wide clientele. That apart, there is an erroneous perception that food product made by using enzymes has enzymes in them. That is not so, as most often enzymes used in the manufacturing process get destroyed in the manufacturing stage itself. If the benefit of biotechnology in the food industry has to gain acceptance then consumer education in that direction is vital. After all civil

society's acceptance of biotechnology food products will be the harbinger for more such biotechnological advance to take place.

Future Prospects of biotechnology in food industry:

A key issue in the sector where the application of biotechnologies could be useful

Emerging pathogens : The identification of infectious agents requires high-end technologies which are not usually available in developing countries. Developing countries must, therefore, seek assistance from countries with higher calibre technologies in order to characterize the infectious agents, put in place surveillance and monitoring systems and develop strategies to contain the diseases. Biotechnology can play a key role in facilitating the characterization of new emerging pathogens. Traditional cultural methods for the detection and enumeration of microbial pathogens are tedious and require at least 12–18 hours for the realization of results. By that time, the food products would have been distributed to retailers or consumers. Immunoassay diagnostic kits facilitate near-real-time monitoring, sensitivity, versatility and ease of use. The emergence of multi-antibiotic resistance traits is prevalent in intensive farming in developing countries due to the abuse of antibiotics. The spread of multi-antibiotic resistant micro-organisms poses public health concerns, because pathogens exhibiting such resistance would be difficult to control with the use of currently available antibiotics. The rapid detection of these pathogens, with high sensitivity, is one way of monitoring and containing the spread of multi-antibiotic resistant traits. A strategic approach being employed by some is the development of affinity biosensors with an antibiotic resistant nucleotide sequence as the detection probe.

Identifying options for developing countries

It is important that countries recognize the potential of fermented foods and prioritize actions to assure their safety, quality and availability. A number of specific options can be identified for developing countries to help them make informed decisions regarding adoption of biotechnologies in food processing and in food safety for the future.

Regulatory and policy issues Governments must be committed to protecting consumer health and interests, and to ensuring fair practices in the food sector. There has to be consensus at the highest levels of government on the importance of food safety, and the provision of adequate resources for this purpose.

Government policy that is based on an integrated food-chain approach is science-based, transparent and includes the participation of all the stakeholders from farm to table must be put in place. The importance of the regional and international dimensions of the use of biotechnologies in food processing and safety must be recognized. Priority must be accorded to promoting fermented foods in the food-security agendas of countries. Governments must also provide an enabling environment that is supportive of the growth and development of upstream fermentation processes such as the production of high-value fermented products, such as enzymes, functional-food ingredients and food additives.

International cooperation and harmonization

The organization and implementation of regional and international fora are critical requirements for the enhancement of national organizational capability and performance and for the facilitation of international co-operation. Further, the setting up of administrative structures with clearly defined roles, responsibilities and accountabilities could efficiently govern processed foods and safety issues.

Biotechnology-based Standard Operating Procedures (SOPs) for food safety should also be documented for use in authorized laboratories. National food control databases for the systematic collection, reporting and analysis of food-related data (food inspection, analysis, etc.) with set regulations and standards based on sound science and in accordance with international recommendations (Codex) are key requirements.

Education policy

While the consumption of fermented foods is growing in popularity among higher-income consumers thanks to increasing interest in wellness through diet, the consumption of fermented foods by lower-income consumers in many developing countries is perceived to be a backward practice. Strategies should therefore be developed for the dissemination of knowledge about food biotechnology and, particularly, fermented foods. Targeted consumer education on the benefits of consuming fermented food products and on applying good practice in their production is required. Food biotechnology should be included in educational curricula in order to improve the knowledge base in countries on the contribution of fermented foods to food and nutritional security and to generate awareness of the growing market opportunities for fermented foods and high-value products derived from fermentation processes.

Information-sharing

Access to specialized technical information on biotechnology and biotechnological developments in the food processing sector are critical and necessary inputs and support systems for guiding and orienting the research agendas of countries. The necessary information systems should therefore be developed to facilitate rapid access to information on biotechnological developments across both the developed and the developing world.

Legislation and policy on technologies

Expertise in legislation and technology licensing, as well as knowledge about how to nurture innovation and turn it into business ventures, are critical requirements for developing countries. Successful technology transfer requires all of these elements and an environment that is conducive to innovation. Government policy in developing countries should therefore prioritize technology transfer that helps create new business ventures, an approach that requires government support such as tax incentives and infrastructure investment.

Intellectual property rights (IPR)

Many of the traditional fermentation processes applied in developing countries are based on traditional knowledge. Enhanced technical and scientific information is required in order to claim ownership of the traditional knowledge of the craft of indigenous fermented foods. Lack of technical knowledge has resulted in the failure to realize the benefits of the industrialization of indigenous fermented foods by individuals who are the rightful owners of the technology.

Greater focus is required on issues of relevance to IPR and on the characterization of microbial strains involved in traditional fermentation processes. Emphasis must be placed on IPR education for scientists. National governments should put in place the requisite infrastructure for IPR to facilitate the process. At the institutional level, this infrastructure would include technology management offices for assisting scientists in procedures relating to intellectual property matters. The processes used in the more advanced areas of agricultural biotechnology are generally covered by IPR, and the rights are generally owned by parties in developed countries.

Communication and consumer perceptions

Communication between various stakeholders is critical in proactively engaging with consumers. Communication must be established with the public at large on processed food and associated hazards. Communication gradually builds confidence and will be critical to advancing the application of biotechnologies in food processing and safety. The primary role of communication in this respect is to ensure that information and opinions from all stakeholders are incorporated in the discussion and decisionmaking process. The need for specific standards or related texts and the procedures followed to determine them should also be clearly outlined. The process, therefore, should be transparent.

- Public awareness and education are critical to the success of food bio-processing and food safety in developing countries.
- Greater attention must be directed toward understanding consumer and producer (processor) perceptions on food safety and quality in developing countries.
- If foods are to be promoted as being safe and healthy, their nutritional and safety attributes must be transparently demonstrated by presenting scientific data to substantiate the nutritional and health benefits and by applying good manufacturing/hygiene practice and HACCP as safety measures to ensure that issues of consumer concern are addressed.

Identifying priorities for action for the international community

The last decade has witnessed considerable change with respect to the application of biotechnology in food processing and food-safety applications. Market forces have been the major drivers of change in the food sector of developing countries. Modern biotechnological tools are likely to play a greater role in the development of efficient science-based processes for food processing and safety in order to respond to consumer demand. The production of high-value fermented products such as enzymes, functional food ingredients and food additives is likely to continue to increase in developing countries.

The international community (FAO, UN organizations, NGOs, donors and development agencies) can play a major role in assisting developing countries to maximize the benefit to be derived from food bioprocessing. The adoption of biotechnology-based methods in food processing and for food safety and quality monitoring is dependent on several factors that include capacity-building in technical and regulatory areas, policy formulation, regulatory frameworks and regional networks.

Capacity-building and human resource development

a) Support for basic and advanced education.

b) Prioritization of specific areas for investment.

c) Development of policies, priorities and action programmes that promote food fermentation as a means of addressing food security.

d) Support for human resource development in a range of scientific disciplines – food biotechnology, food safety, bioengineering and enzyme technology. e) Support for capacity-building initiatives for household-level, small- and medium-scale processors of fermented foods.

f) Support for IPR development.