

# The Role of Biotechnology in Food Production and Processing

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**Abstract:** Biotechnology is the use of living systems and organisms to develop or make useful products, or any technological applications that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use. Depending on the tools and applications, it often overlaps with the fields of bioengineering and biomedical engineering. Some of the applications were identified in this paper to include biotechnology in food fermentation to enhance properties such as the taste, aroma, shelf-life, texture and nutritional value of food. Biotechnology in the production of enzymes to bring about desirable changes in food, biotechnology in the production of food ingredients; flavours, fragrances, food additives and a range of other high valued-added products, genetically modified starter cultures, genetically modified foods, the use of all these modern technologies in diagnostics for food testing, the role of biotechnology in food production by increasing food production, improved harvesting, storage and nutritional value, better raw materials, better flavour and the production of food containing vaccines, the safety of food produced with biotechnology as well as the risks and benefits of biotechnology in food production.

**Keywords:** Biotechnology, Bioengineering, Fermentation, Enzymes, Food, Microorganisms

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## 1. Introduction

Biotechnology is defined as any technological application that uses biological systems, living organisms or derivatives thereof to make or modify products or processes for specific use (UN Convention on Biological Diversity, 2002). 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 microorganisms 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. 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 (Food and Agricultural Organisation, FAO, 2010).

Food processing is defined as the transformation of raw ingredients into food or of food into other forms. Food processing typically takes clean, harvested crops or butchered animal products and uses these to produce attractive, marketable and often long shelf life food products. 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 (Codex Alimentarius Commission, CAC, 2009).

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 (CAC, 2009). 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 (FAO, 2010).

## 2. Application of Biotechnology in Food Processing

### 2.1. Biotechnology in Food Fermentation

Microorganisms are 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, consistency and general acceptability) (Leuchtenberger *et al.*, 2005), 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) (Bauer *et al.*, 2007).

Fermented foods are consumable products that are generated from thermally treated or untreated food raw materials of plant or animal origin. They have characteristic sensory and nutritional value as well as properties determining shelf life, hygiene or practical value that are decisively affected by microorganisms and/or enzymes (from the raw material) (Aguirre and Collins, 1993).

About one third of all food currently being consumed is fermented. These fermented foods feature a number of advantages:

1. They offer a high degree of hygienic safety.
2. They have an increased shelf life compared to the raw product.
3. Raw materials are refined by improving quality-determining properties.
4. Toxic or harmful substances derived from the raw material, such as cyanides, hemagglutinins, goitrogens, proteinase inhibitors, phytic acid, oxalic acid, glucosinolates and indigestible carbohydrates, are partly degraded.
5. Manufacture requires only basic technology and low energy consumption.
6. They meet a demand for natural and organic food.

Some examples of fermented foods are cheese, idli, dosa, buttermilk etc. Below are the production processes for some of these fermented foods. The basic processes remain the same for these fermented food production but the temperatures and detailed procedures differ from company to company (FAO, 2010).

#### *Yoghurt Production*

Microorganism: *Lactobacillus bulgaricus* and *Streptococcus thermophilus* (1:1 ratio) are employed as starter cultures. The production of yoghurt is as follows:

1. Add milk with reduced water content (15-20%) or standardised yogurt mix (1-2% milk fat)
2. To the mix add a stabilizer
3. Pasteurize the mixture at 95°C for half an hour
4. Homogenise and cool
5. Add starter culture and mix
6. Incubate the mixture at 43°C while maintaining the pH at 4.5
7. Cool and package.

The yoghurt can be stored for up to a month at refrigeration temperature between 4 and 5°C.

#### *Buttermilk Production*

Microorganism: *Streptococcus lactis* and *Streptococcus cremoris*, *Lecunostoc cremoris* are employed as starter cultures. The production of buttermilk is as follows:

1. Add standardized milk with 10 % non-fat milk solids and 0.5% milk fat.
2. Heat treat the standardised milk at 85°C for 30 minutes or 88-91°C for 2-5 minutes.
3. Homogenize and add starter culture.
4. Incubate at 22°C for 14-16 hours at pH 4.5.
5. Allow the butter milk to cool then package.

#### *Cheese Production*

Microorganisms:

*Streptococcus lactis*, *Streptococcus cremoris*, *Lactobacillus lactis* (for curd formation) are employed as starter cultures while *Penicillium roquefortii*, *P. cammebertii* are employed for ripening).

The production of cheese is as follows:

1. Milk is mixed with bacterial starter culture and calcium ions which produces lactic acid from lactose and lowers the pH to 4.6.
2. Rennet digests casein in the milk while lipase digests the lipids.
3. The coagulum is cooked to inactivate rennet.
4. Whey is separated from the curd.
5. Salting.
6. Protein and lipid hydrolysis
7. The curd is pressed and ripened to produce cheese.

#### **2.1.1. Traditional Approaches in Genetic Improvement of Starter Cultures**

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 (Barallon *et al.*, 1996).

##### *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 (Lemaux, 2010).

##### *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 (Lemaux, 2010). 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) (Lemaux, 2010).

##### *c) Hybridisation (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 (Ronald and McWilliams, 2010).

#### **2.1.2. Molecular Approaches in Improvement of Starter Cultures**

##### *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 bioprocessing 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) (Bessin *et al.*, 2000)

Genetically Modified (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 utilise the carbohydrate present in conventional feedstocks). None of these GM yeasts are, however, used commercially (Parkhill *et al.*, 2000).

##### *b) Genetic Characterization*

The genetic characterisation of microbial strains through the use of molecular diagnostic techniques can contribute tremendously to the understanding of fermentation processes (De Vos, 2001). 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 (De Vos, 2001).

##### *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 eukaryote to have its genome sequenced in 1996) and large numbers of microbial genome sequencing projects are also underway (<http://www.ncbi.nlm.nih.gov/entrez/query>). 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 (Parkhill *et al.*, 2000). 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. For example, a recent paper by Cooper and colleagues (<http://www.pubmedcentral.nih.gov/articlerender>) describes their use of DNA macro arrays 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 (Parkhill *et al.*, 2000).

## 2.2. 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 (Lick *et al.*, 1996).

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 (Olempska-Beer *et al.*, 2006). 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 (Teuber, 1993).

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 (Olempska *et al.*, 2006).

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 (Teuber, 1993). 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 (Teuber, 1993).

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 thermo stability 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 (Barallon *et al.*, 1996).

**Table 1.** Marketed Enzymes Produced Using Gene Technology.

Principal enzyme activity	Application
Alpha- acetolated decarboxylase	
Alpha- amylase	Brewing
Catalase	Baking, brewing, distilling, starch
Chymosin	Mayonnaise
Beta-glucanase	Cheese
Alpha-glucanotransferase	Brewing
Glucose isomerase	Starch
Glucose oxidase	Starch
Hemicellulase	Baking, egg, mayonnaise
Lipase	Baking
Maltogenic amylase	Fats, oils
Microbial rennet	Baking, starch
Phytase	Dairy
Protease	Starch
Pullulanase	Baking, dairy, distilling, fish, meat, starch, vegetable
Xylanase	Brewing, starch
Source:(Olempska beer <i>et al.</i> , 2006)	Baking, starch

## 2.3. Biotechnology in the Production of Food Ingredients

Food ingredients are substances used to increase nutritional value, change consistency and enhance flavour (Leuchtenberger *et al.*, 2005). The compounds are substances nature has provided and are usually of plant or microbial origin – the common food and personal care ingredients xanthan gum and guar gum are produced by microbes. Many of the amino acid supplements, flavours, flavour enhancers and vitamins added to breakfast cereals are produced by microbial fermentation (Wu, *et al.*, 2009). Specialized high-purification systems remove all microbes prior to final food

production (Braunschweiger and Conzelmann, 1997).

Enzymes are used as processing aids to enhance the efficiency of food manufacture. For example, chymosin, used to make cheese, is an enzyme that occurs naturally in the stomachs of animals. Biotechnology scientist's years ago created a way for yeasts, molds and bacteria to produce chymosin, eliminating reliance on livestock for this enzyme (Teuber, 1993).

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 (Beaumont, 2002). 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 (Braunschweiger and Conzelmann, 1997).

**Table 2.** Food Ingredients Used in Food Production.

Types of Ingredients	What They Do	Examples of Uses	Names Found on Product Labels
Preservatives	Prevent food spoilage from bacteria, molds, fungi, or yeast (antimicrobials); slow or prevent changes in colour, flavour, or texture and delay rancidity (antioxidants); maintain freshness.	Fruit sauces and jellies, beverages, baked goods, cured meats, oils and margarines, cereals, dressings, snack foods, fruits and vegetables.	Fruit sauces and jellies, beverages, baked goods, cured meats, oils and margarines, cereals, dressings, snack foods, fruits and vegetables.
Sweeteners	Add sweetness with or without the extra calories.	Beverages, baked goods, confections, table-top sugar, substitutes, many processed foods.	Sucrose (sugar), glucose, fructose, sorbitol, mannitol, corn syrup, high fructose corn syrup.
Colour Additives	correct natural Variations in color; enhance colors that occur naturally; provide color to colorless and "fun" foods.	Many processed foods, (candies, snack foods margarine, cheese, soft drinks, jams/jellies, gelatins, pudding and pie fillings).	FD&C Blue Nos. 1 and 2, FD&C Green No. 3, FD&C Red Nos. 3 and 4, FD&C Yellow Nos. 5 and 6, Orange B, Citrus Red No. 2, annatto extract, beta-carotene.
Flavors and Spices	Add specific flavors (natural and synthetic)	Pudding and pie fillings, gelatin dessert mixes, cake mixes, salad dressings, candies, soft drinks, ice cream, BBQ sauce	Natural flavoring, artificial flavor, and spices
Flavor Enhancers	Enhance flavors already present in foods (without providing their own	Many processed foods	Monosodium glutamate (MSG), hydrolyzed soy protein, autolyzed yeast extract.

Source: (<http://www.advancesfoodprocessingconference.com/index.html>) (2014).

#### 2.4. Starter Cultures

Starter cultures are preparations of live microorganisms or their resting forms, whose metabolic activity has desired effects in the fermentation substrate, the food. The preparations may contain unavoidable residues from the culture substrate and additives that support the vitality and technological functionality of the microorganisms (such as antifreeze or antioxidant compounds) (Holzapfel, 2002).

Starter cultures have mainly a technological function in the food manufacturing. They are used as food ingredients at one or more stages in the food manufacturing process and develop the desired metabolic activity during the fermentation or ripening process. They contribute to the one or multiple unique properties of a foodstuff especially in regard to taste, flavour, colour, texture, safety, preservation, nutritional value, wholesomeness and/or health benefits. (Wu *et al.*, 2009)

The use of 'defined cultures' allows for a greater degree of control over the fermentation process. Mäyrä-Mäkinen and Bigret (1998) made a distinction between:

- Single-strain cultures: contain one strain of a species;
- Multi-strain cultures: contain more than one strain of a single species;

c. Multi-strain mixed cultures: contain different strains from different species. These different cultures are used in the fermentation of milk, meat, wine, fruit, vegetables and cereals.

**Table 3.** Some Uses of Starter Culture in Food Production.

Product	Raw material	Starter culture
		Yeast
Beer	Cereal	Yeast, lactic acid bacteria
Wine	Grape juice	Yeast, lactic acid bacteria
Bread	Grains	Mould ( <i>Aspergillus</i> ),
Soy sauce	Soya beans	Lactic acid bacteria
Sauerkraut, Kimchi	Cabbage	Lactic acid bacteria
Fermented Sausages	Meat	Lactic acid bacteria
Pickled vegetables	Cucumbers, olives	Lactic acid bacteria
	a. o.	
Fermented milks	Milk	Lactic acid bacteria,
Cheese	Milk	yeast, mould

Source: (Wu *et al.*, 2000).

##### 2.4.1. Genetically Modified (GM) Starter Culture

The aim of genetic engineering here is to modify starter cultures (bacteria or yeast fungi) which are vital in bread, beer, yoghurt, cheese and salami production, in such a way that they accelerate the production process, while at the same

time increasing the yield or intensifying taste (Hutkins, 2006).

In 1995 and 1999 licences were issued in the United Kingdom for brewers and baker's yeast that were used on a temporary basis in pilot production. Genetically engineered *Streptococcus* used a starter culture in yoghurt another model system for detecting a genetically modified microorganism was elaborated for *Streptococcus thermophilus*, a bacterial strain used as a starter culture in yoghurt (LMBG-Methodensammlung, in preparation). The method is analogous to the methods described before; again, the DNA extraction procedure was somewhat optimised (Lick *et al.*, 1996). Since certain results of the inter-laboratory studies were still unavailable as of January 1997; a precise assessment on its reliability cannot yet be provided. The primers recognise sequences of the homologous lacZ gene and the (heterologous) chloramphenicol acetyl transferase (cat), which represents the transgene in this model-GMO (Heller, 1995). The amplicon used was 623 basepairs in size and contains an interface between homologous and heterologous sequences, ensuring high specificity of the method. As a positive control, species-specific PCR amplification of the lacZ sequences from *Streptococcus thermophilus* was used.

#### 2.4.2. Genetically Modified (GM) Foods

Genetically modified (GM) foods are those produced from organisms with modified genetic material (DNA) e.g. through the insertion of a gene from another organism. Most of the currently available GM foods are derived from plants, with possibility of GM food production from GM animals or microorganisms in the near future. Ensuring an adequate supply of food for the booming population of today's world will be a major challenge in years to come (Wu, *et al.*, 2009). The introduction of GM foods can meet the need of proper a surplus food supply in a quite a number of ways as follows:

1. Pest resistance: Crop damage from insect pests is a devastating loss for farmers also resulting in starvation in developing countries. Tons of chemical pesticides are applied to the crop fields annually, which the consumers do not wish to eat because of potential risks to health. Production of GM foods such as *Bacillus thuringiensis* (Bt) corn help eliminate the application of chemical pesticides and reduce the cost of bringing a crop to market (Aris and Leblanc, 2011).

2. Herbicide tolerance: Large quantities of various types of herbicide or weed-killer are sprayed to destroy weeds. This is an expensive process that requires careful handling so as to protect the crops and environment from the harmful effects of herbicides. Genetically modified crop plants should be synthesized in a way to be resistant to one or more harmful herbicides could protect the environment by minimizing the quantity of herbicides applied. As, for example, a strain of genetically modified soybeans has been developed by Monsanto that is not damaged by the herbicide product. When grown these soybeans only require a single application of the required herbicide instead of a number of applications, thereby reducing cost of production and reducing the dangers

of environmental damage (Aris and Leblanc, 2011).

3. Cold tolerance: Extreme cold can destroy some crop plants. A gene from cold water fish has been inserted into certain plants such as potato and tobacco that are capable of tolerating frost (Heller, 1995).

4. Drought tolerance/salinity tolerance: As the world population grows and more land is utilized for housing instead of food production, farmers will need to grow crops in locations previously unsuited for plant cultivation. Creating plants that can withstand long periods of drought or high salt content in soil and groundwater will help people to grow crops in formerly inhospitable places (Heller, 1995).

5. Nutrition: People in third world countries rely mainly on one crop plant such as rice as the main staple food. But rice lacks adequate amounts of all the necessary nutrients. A new strain of "golden" rice has been developed by the researchers at the Swiss Federal Institute of Technology, Institute for Plant Sciences with an unusually high beta-carotene (vitamin A) (Visakh *et al.*, 2013).

6. Pharmaceuticals: Certain drugs and vaccines are often costly to manufacture and also require special storage facilities quite unavailable in third world countries. Research is being carried out to develop edible vaccines in plants such as tomatoes and potatoes which will be much easier to store and administer as compared to the traditional vaccines that are injected (Singh, 2013).

#### SOME GENETICALLY MODIFIED FOODS

##### 1. Biotechnology Soybean

Soybean is the oil crop of greatest economic relevance in the world. Its beans contain proportionally more essential amino acids than meat, thus making it one of the most important food crops today. Processed soybeans are important ingredients in many food products (Shurtleff and Aoyagi, 2008).

a) Herbicide-tolerant soybean: Herbicide tolerant soybean varieties contain a gene that provides resistance to one of two broad spectrum herbicides.

This modified soybean provides better weed control and reduces crop injury. It also improves farm efficiency by optimizing yield, using arable land more efficiently, saving time for the farmer, and increasing the flexibility of crop rotation. It also encourages the adoption of no-till farming-an important part of soil conservation practice (Edmund and Mian, 1995).

These varieties are the same as other soybeans in nutrition, composition, and in the way they are processed into food and feed (Edmund and Mian, 1995).

b) Insect resistant soybean: This biotech soybean exhibits resistance to lepidopteron pests through the production of Cry1Ac protein. Insect resistant soybean was developed to reduce or replace high insecticide applications and at the same time maintain soybean yield potential (Edmund and Mian, 1995).

c) Oleic acid soybean: This modified soybean contains high levels of oleic acid, a monounsaturated fat. According to health nutritionists, monounsaturated fats are considered "good" fats compared with saturated fats found in beef, pork,

cheese, and other dairy products. Oil processed from these varieties is similar to that of peanut and olive oils. Conventional soybeans have an oleic acid content of 24%. These new varieties have an oleic acid content that exceeds 80% (Singh *et al.*, 2008).

### 2. Biotechnology Maize

Maize is one of the three most important grains of the world. It is used as livestock feeds, processed as cooking oil and food additives, and currently as feedstock for biofuels (Butler, 1996).

a) Herbicide-tolerant maize: These maize varieties work in a similar manner to herbicide-tolerant soybean. They allow growers better flexibility in using certain herbicides to control weeds that can damage crops (Butler, 1996).

b) Insect-resistant maize: This modified maize contains a built-in insecticidal protein from a naturally occurring soil microorganism (Bt) that gives maize plants season-long protection from corn borers. This means most farmers do not have to spray insecticide to protect maize from harmful pests, which can cause significant damage and yield loss in many areas. Bt maize also reduces toxin contamination arising from fungal attack on the damaged grain. The Bt protein has been used safely as an organic insect control agent for over 40 years (Aris and Leblanc, 2011).

### 3. Biotechnology Rice

Rice is life for more than half of humanity. It is the staple food for over 3 billion people, more than 90% of whom are Asians (Wang and Hesseltine, 1981).

a) Herbicide-tolerant rice: These rice varieties work in a similar manner to herbicide-tolerant soybean. They contain a gene that provides resistance to one of two broad spectrums, environmentally benign herbicides. (Aris and Leblanc, 2011)

b) Insect-tolerant rice: This modified rice works in a manner similar to insect-resistant maize. It reduces yield losses caused by caterpillar pests, the most important of which are the yellow stem borer in tropical Asia and the striped stem borer in temperate areas (Aris and Leblanc, 2011).

### 4. Biotechnology Tomato

#### Delayed-ripening tomato

The delayed-ripening tomato became the first genetically modified food crop to be produced in a developed country. These tomatoes spend more days on the vine than other tomatoes, thus resulting in better flavour. Furthermore, the longer shelf life has commercial advantages in harvesting and shipping that can reduce the costs of production (Wang and Hesseltine, 1981).

### 5. Biotechnology Cotton

a) Herbicide-tolerant cotton: This cotton works in a manner similar to other such crops. For benefits, see herbicide-tolerant soybean (Singh, 2013).

b) Insect-resistant cotton: This modified cotton works in a manner similar to insect resistant corn. It contains a protein that provides the plant with season-long protection from budworms and bollworms. The need for additional insecticide applications for these pests is reduced or eliminated (Singh, 2013).

### 6. Biotechnology Potato

a) Insect-resistant potato: This biotech potato works like insect resistant maize. It contains a protein that provides the plant with built-in protection from the Colorado potato beetle. Thus, this potato needs no additional protection for this pest, benefiting farmers, consumers, and the environment (Alyokhin *et al.*, 2008).

b) Virus-resistant potato: Several potato varieties have been modified to resist potato leaf roll virus (PLRV) and potato virus Y (PVY). In the same way that people get inoculations to prevent disease, these potato varieties are protected through biotechnology from certain viruses. Furthermore, virus resistance often results in reduced insecticide use, which is needed to control insect vectors that transmit viruses (Alyokhin *et al.*, 2008).

### 7. Biotechnology Canola

Canola is a genetic variation of rapeseed and was developed by Canadian plant breeders specifically for its nutritional qualities, particularly its low level of saturated fat (Ronald *et al.*, 2010).

a) Herbicide-tolerant canola: Herbicide tolerant canola contains transgenes conferring tolerance to herbicides. This is similar to the trait exhibited by herbicide-tolerant soybean (Aris and Leblanc, 2011).

b) Highlaureate canola: These canola varieties contain high levels of laurate. Oil processed from these novel varieties is similar to coconut and palm oils. This new canola oil is being sold to the food industry for use in chocolate candy coatings, coffee whiteners, icings, frostings, and whipped toppings. Benefits extend even to the cosmetics industry (Aris and Leblanc, 2011).

### 8. Biotechnology Alfalfa

Alfalfa is one of the most important legumes used in agriculture James and Clive (1996).

Herbicide-tolerant alfalfa: This alfalfa works in a manner similar to other such crops (Aris and Leblanc, 2011).

### 9. Biotechnology Papaya

Virus-resistant papaya: This Hawaiian-developed papaya contains a viral gene that encodes for the coat protein of papaya ring spot virus (PRSV). This protein provides the papaya plant with built-in protection against PRSV. This biotech papaya works in a manner similar to virus resistant potato (Gonsalves, 2004).

### 10. Biotechnology Squash

Virus-resistant squash: A biotech yellow crookneck squash is now able to resist watermelon mosaic virus (WMV) and zucchini yellow mosaic virus (ZYMV). These new varieties contain the coat protein genes of both viruses. This biotech approach bypasses aphid control, which may reduce or eliminate the use of insecticides (Gonsalves, 2004).

### 11. Biotechnology Sugar Beet

In 2008, an herbicide tolerant sugar beet variety was planted in Canada and USA for the first time. The herbicide tolerant sugar beet allows farmers to cut the number of required cultivations by half (Singh *et al.*, 2008).

### 2.5. 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 (Barallon *et al.*, 1996). 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 micro flora in foods (Ronald *et al.*, 2010). 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 (Barrett, 1997). 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 foodborne illnesses. Monoclonal and polyclonal antibodies can also be used for diagnostics, e.g. in enzyme-linked immunosorbent assay (ELISA) kits (Henkel, 1995).

Microarrays are biosensors which consist of large numbers of parallel hybrid receptors (DNA, proteins, and 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 (Barallon *et al.*, 1996).

Specific areas of food processing where advances are being seen are:

- a) Bread-making: for which improved strains of yeast have been developed containing genes for production of other food processing aids, such as amylases, which give improved dough (Hutkins, 2006). Yeast can also be used to produce a range of enzymes for use in processes such as cheese production, where introducing a copy of a calf gene has given a strain of yeast which produces the enzyme, chymosin. Previously, this enzyme could only be obtained from the stomachs of calves. (Teuber, 1993)
- b) Fruit juice production: where juice yields from apples

can be improved by adding pectinase enzymes. These are produced naturally by a strain of the mould *Aspergillus*. The rate at which the enzymes are made can be improved by transferring the gene for pectinase from one strain of the mould into a second strain with a higher capacity for enzyme production. (Barallon *et al.*, 1996)

- c) Improved quality management and food safety: through a greater understanding of micro-organisms and enzymes in food production. A range of biological tools, such as monoclonal and polyclonal antibodies, will add to this impact through their use in a range of diagnostic tests aimed at enhancing the quality and safety of products and processes. These can potentially be used to monitor the presence of additives, toxins, pesticides, micro-organisms and antibiotics, and they will give quicker, more accurate detection than traditional laboratory processes. (Institute of Food Technologists <http://www.ift.org>).

## 3. Role of Biotechnology in Food Production

### a) Increased Production

Biotechnology can be used in many ways to achieve higher yields; for example by improving flowering capacity and increasing photosynthesis or the intake of nutritive elements. In the long term, genetic engineering will also help to increase production of the most valuable components of specific crops. Cassava and rice, for example, are the main sources of: calories for millions of people. However, the protein content of both staples is low and, for those who lack access to a variety of foods, this may lead to a diet which is not well balanced. Genetic engineering can be used to modify the amino acid composition of plant proteins in order to increase the nutritional value of these staple crops (James, 2010).

Productivity increases may lead to lower prices. Certainly, this would benefit the final consumer but the situation of the producers would not necessarily improve. The income position of the rural population is affected by such factors as:

- a) Changes in the prices farmers receive;
- b) The effect of the new technology on production costs;
- c) The impact of the new technologies on the volume of production as well as the effects of these changes on the demand for labour; and
- d) The impact on the costs of their own consumption.

Whether or not rural households are able to adapt to the new technologies themselves will also affect their incomes, as will their position as net buyers or net sellers. Accordingly, various segments of the rural population will be affected in very different ways as a result of specific applications of biotechnology in a given country (James, 2010).

### b) Improved Harvesting

The cloning of plants can help to reduce the work necessary for harvesting. When individual plants show more

uniform characteristics, grow at the same speed and ripen at the same time, harvesting will be less laborious. A reduction in the workload is not only an objective in highly industrialized countries, it can also be very important for small farmers in developing countries, especially women who are already overburdened with many other tasks (James, 1996).

#### c) Improved Storage

Food shortages would not exist in many countries if the problem of post-harvest losses could be solved. Microbiological reactions by toxicogenic, infective and spoilage micro-organisms cause the greatest losses. Biotechnology may contribute to solving these problems (James, 1996).

In the future, genetic engineering may be used to remove plant components that cause early deterioration of the harvest. For instance, a technique to reduce the presence of a normal tomato enzyme involved in the softening of ripe tomato fruit has been patented. The technique involves engineering plants with an antisense1 gene so that production of the enzyme is significantly reduced (Cheruvu and Mahalik, 2008).

Improved storage and better transport of food would increase the quantity of food available and improve the possibilities for a more elaborate division of labour between different districts and regions. However, this could also affect some producers adversely if they were unable to withstand increased competition and they would therefore lose their market position. As a further consequence, much of the income upon which their food consumption depends would be lost (Cheruvu and Mahalik, 2008).

#### d) 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. 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 (Singh *et al.*, 2008).

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 (James, 2013).

#### e) 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  $\omega$ -3-fatty acids). These have been linked to brain development and have potential in a range of speciality, clinical and infant foods (Singh *et al.*, 2008).

#### f) Better Flavour.

For example, 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 (Valyasevi and Rolle, 2006).

#### g) Production of Food containing Vaccines.

Currently under development is the production of a cholera vaccine in potatoes. Eating these potatoes would allow easier and greater immunization to the world's population. This is important because cholera is a significant cause of diarrhoea and death in third world countries (Leumax, 2000).

h) 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 (James, 1996).

i) Reduced levels of toxicants, allowing a wider range of plants to be used as food crops, such as the edible strain of sweet lupin which has been developed (James, 1996).

## 4. Safety of Food Produced With Biotechnology Processes

Based on strong scientific evidence and consensus among a broad representation of scientific and governmental bodies, there is no known food safety concern related to consuming food produced through biotechnology. A number of food and health organizations such as the American Medical Association and the Institute of Food Technologists recognize and support the use of food biotechnology (Institute of Food Technologists <http://www.ift.org>).

### Labelling Requirements

The FDA has decided that this new technique for changing the genetic makeup of plants and animals does not differ significantly from traditional plant and animal breeding techniques. Therefore, no special labelling will be required. However, common food allergy proteins would require labelling. For example, if genetic material from a peanut is put into a tomato, the tomato would require labelling. The special labelling requirement would let people with an allergy to peanuts know that the tomato may contain peanut proteins which could cause an allergic reaction (FAO, 2010).

## 5. Benefits and Risks of Biotechnology in Food Production

- i. Benefits of Biotechnology in Food Production
  - a) The number one advantage of biotechnology is the increased production of food. Biotechnology has made it possible to produce crops that are disease resistant, drought resistant so the yield of the crops is increased dramatically. The increased production of food has made it possible to feed the growing population. Increased quantity of food also means that consumers will pay a decent price for the food.
  - b) Biotechnology has also made it possible to grow crops without the use of much chemicals, pesticides and herbicides since the GM crops already have built in immunity to diseases and pests. This means that GM crops are environment friendly and will spare environment unlike the usual crops which required a bundle of chemicals to be sprayed on them which afterwards damaged the environment.
  - c) Due to biotechnology, the cost of producing crops is decrease since the need for pesticides and herbicides is decreased. This had increased efficiency in the field of agriculture and reduced the overall cost. This also means that the consumers are also not going to have to pay a lot of money for the food since the cost of producing it was less.
  - d) Some GM crops produced by biotechnology are also high in some nutrients that ordinary crops are not high in. This is a very good benefit of biotechnology, since it is very healthy for the consumers to get the extra nutrients from GM crops. For example, golden rice which has extra iron and Vitamin A which can help save people from going blind in undeveloped countries due to vitamin A deficiency.
  - e) Another benefit from biotechnology is that it has increased the shelf life of some crops which is a good trait for the producers, seller and consumers. It will make food to stay fresh longer.
- ii. Risks of Biotechnology in Food Production
  - a) One fear from the use of biotechnology is that the genes could be transferred to other crops which they are not intended to go in and lead to problem, since the transfer of the genes would not be known. Consumers could get an allergic reaction to the food when they consume food that is contaminated with the gene or bacteria transmitted through cross-pollination unknowingly.
  - b) Seeds of GM crops are relatively higher in cost, so the poor farmers have a hard time reaching them.
  - c) With biotechnology, there is some fear of health risks that might not be known now and developed later. This would really be devastating as the use GM crops increasing throughout the world.

## 6. Future of Food Biotechnology

As research and development in the field of food

biotechnology continues, scientists may discover a faster way to detect unwanted viruses and bacteria that may be present in food. This may help decrease the risk of foodborne illnesses and aid in keeping food safe to eat.

Crops produced through biotechnology that are able to grow in harsh environmental conditions, such as extreme heat or drought, are also being developed. This may lead to crop planting on land that may have once been unsuitable for agriculture.

Scientists have also begun to target certain allergy-causing proteins in foods, so that people with food allergies may one day be able to consume previously allergenic foods safely.

Applying food biotechnology may also provide more healthful foods for people and animals. Foods with enhanced nutritional traits are on their way to the supermarket shelves. Through food biotechnology, foods may help to combat chronic diseases by providing more healthful compounds, including increased levels of antioxidants, vitamins, and decreased amounts of unhealthy fats (Council for Agricultural Science & Technology <http://www.cast-science.org>).

## 7. Conclusion

The benefits of biotechnology over weigh the downside in today's date. Since, it is really important to increase the production of food to meet the needs of growing population. While, the safety of the Genetically Modified (GM) crops is tested fist by U.S. Department of Agriculture (USDA), Food and Drug Administration (FDA) and Environmental Protection Agency (EPA) before any GM crop is given permission to grow and sell.

## Recommendations

- a) The technical capabilities of academic and research institutes should be strengthened in the fields of biotechnology, food processing, bioprocess engineering and food safety through training and exchange programmes for researchers.
- b) Finding in the area of biotechnology should be encouraged and consistence.

## Glossary

Bt: *Bacillus thuringiensis*, a common soil bacterium that produces a protein toxic to certain insects.

Coat protein (CP): a major component of viruses. CPs protects viral genetic information.

Enzyme: a protein that regulates chemical reactions inside every living cell and organism.

Gene: a biological unit that determines an organism's inherited characteristics.

Herbicides: chemicals frequently used in agriculture to control weeds that compete with crops for soil nutrients, water and sunlight.

Laurate: an important fatty acid used in the food industry, mainly sourced from coconut and palm oil.

Oleic acid: a monounsaturated fatty acid found in animal and vegetable oils. Monounsaturated fats are the most benign of the fat sources and are generally considered safe as they do not cause disease or other health problems.

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