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The impact of genetic modification of human foods in the 21st century: A review

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Abstract

Genetic engineering of food is the science which involves deliberate modification of the genetic material of plants or animals. It is an old agricultural practice carried on by farmers since early historical times, but recently it has been improved by technology. Many foods consumed today are either genetically modified (GM) whole foods, or contain ingredients derived from gene modification technology. Billions of dollars in U.S. food exports are realized from sales of GM seeds and crops. Despite the potential benefits of genetic engineering of foods, the technology is surrounded by controversy. Critics of GM technology include consumer and health groups, grain importers from European Union (EU) countries, organic farmers, environmentalists, concerned scientists, ethicists, religious rights groups, food advocacy groups, some politicians and trade protectionists. Some of the specific fears expressed by opponents of GM technology include alteration in nutritional quality of foods, potential toxicity, possible antibiotic resistance from GM crops, potential allergenicity and carcinogenicity from consuming GM foods. In addition, some more general concerns include environmental pollution, unintentional gene transfer to wild plants, possible creation of new viruses and toxins, limited access to seeds due to patenting of GM food plants, threat to crop genetic diversity, religious, cultural and ethical concerns, as well as fear of the unknown. Supporters of GM technology include private industries, research scientists, some consumers, U.S. farmers and regulatory agencies. Benefits presented by proponents of GM technology include improvement in fruit and vegetable shelf-life and organoleptic quality, improved nutritional quality and health benefits in foods, improved protein and carbohydrate content of foods, improved fat quality, improved quality and quantity of meat, milk and livestock. Other potential benefits are: the use of GM livestock to grow organs for transplant into humans, increased crop yield, improvement in agriculture through breeding insect, pest, disease, and weather resistant crops and herbicide tolerant crops, use of GM plants as bio-factories to yield raw materials for industrial uses, use of GM organisms in drug manufacture, in recycling and/or removal of toxic industrial wastes. The potential risks and benefits of the new technology to man and the environment are re-

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viewed. Ways of minimizing potential risks and maximizing the benefits of GM foods are suggested. Because the benefits of GM foods apparently far outweigh the risks, regulatory agencies and industries involved in GM food business should increase public awareness in this technology to enhance worldwide acceptability of GM foods. This can be achieved through openness, education, and research.

Keywords: Genetically modified foods; Agricultural biotechnology; Health; Environment; Controversy; Risks and benefits

1. Introduction

Genetic engineering is described as the science whereby the characteristics of an organism are deliberately modified by the manipulation of the genetic material, especially DNA, and transformation of certain genes to create new variations of life. By manipulating the DNA in various ways and transferring it from one organism to another (the so-called recombinant DNA technique), it has been possible to introduce traits of almost any organism to a plant, bacteria, virus, or animal. Such transgenic organisms are now programmed to manufacture in bulk, various substances such as enzymes, monoclonal antibodies, nutrients, hormones, and various pharmaceutical products including drugs and vaccines (Brown, 1996; Campbell, 1996). Other compounds commercially produced include foods, pesticides, cells, tissues, organs, and biochemicals. It has also been possible to clone some organisms such as bacteria, plants, fish, and even livestock. This technique is now used to modify or transform the plants and animals we use today for food. The ability to manipulate genetic material, and transfer it from one species to another for some economic purposes, is the bedrock of the biotechnology industry. The potential for gene splicing techniques and other biotechnological procedures such as cloning have been compared in the popular press with the discovery of fire, invention of the printing press, and the splitting of the atom.

Plant biotechnology involves the use of microbes or biological substances to perform specific processes in plants for the benefit of mankind. This is done by creating species in which plant metabolism is tailored to provide raw material with respect to quality, functionality, and availability. As a result, many food plants have been genetically modified for various purposes. Food crops that are being produced or modified by genetic engineering techniques are known by various names in literature. Such names include genetically engineered plants, bio-engineered plants, genetically modified organisms (GMOs), genetically modified (GM) crops, or biotech plants (Liu, 1999; Wilkinson, 1997). Many important crops are already being grown from seeds engineered with built-in immunity to herbicides, viruses, insects, and disease. From GM plants are derived ingredients (e.g. oils, flours, meals, syrups, flavors, colorants), whole foods, food products, and feed used in various industries. Several genetically modified foods are expected to hit the market in the next few years (BIO, 1998; Maryanski, 1995). As shown in Table 1, more than half of all processed foods in the USA already contain genetically engineered soy, corn, canola, cotton, or potato products (Allen, 1999a,b; Hsu, 1999a; Lustgarden, 1994a; Wilkinson, 1997).

Table 1
Grocery store foods and products containing GM ingredients

Grocery store food/product	GM component
Pickles	Dextrose from corn, corn syrup
Milk	Recombinant bovine growth hormone
Soda/Soft drink	Corn syrup
Catsup	Tomatoes, corn syrup
Fruit drinks	Corn syrup, dextrose from corn
Bread	Yeast, corn syrup, soybean oil, cornstarch, soy flour, dextrose from corn
Aspirin	Corn starch
Honey	GM enzymes (alpha amylase)
Beer	Corn, yeast, enzymes
Some antibiotics	Corn starch
Tomatoes/peppers	Genes from bacteria and viruses
Breakfast cereals	Corn, corn syrup, soybean oil
Peanuts	Longer shelf-life peanuts
Peanut butter	Peanuts, cottonseed oil, soybean oil, dextrose from corn, corn syrup
Food tenderizers	Food enzymes
Candy and gum	Corn syrup, corn starch, dextrose from corn, soyflour
Cookies	Corn starch, corn syrup, corn flour, canola oil, soybean oil, cotton seed oil
Breakfast pastries (waffles, toasters, pop-tarts, swirls)	Corn syrup, soybean oil, soyflour, corn flour
Chips	Potatoes, cottonseed oil

Sources: BIO 1998, National Corn Growers Association, American Soybean Association. Alliance For Better Foods (www.betterfoods.org).

2. The GM food controversy

Genetic engineering is aimed at benefiting mankind. Therefore food manufacturers would never purposely use a known toxin or allergen because it is not in the manufacturers' interest to market foods that would hurt their customers, consumers, or anyone. In addition, GM food manufacturers subject such foods to more rigorous testing than is required of traditionally bred fruits and vegetables or animals. Despite these well-intentioned measures, genetic modification of foods has been surrounded by controversy since the early 1990s. The cloning of Dolly the sheep in Scotland (Wilmut et al., 1997) sparked several controversial debates, skepticism and speculations, not only about cloning but also other aspects of genetic engineering (Annas, 1997; Krauthammer, 1997). Some people fear that the fast pace of research in genetic engineering may some day lead to cloning of humans which is strongly opposed in the United States and Great Britain (Masci, 1997; Woodard and Underwood, 1997). Some critics totally oppose any form of genetic engineering in plants or animals (including primates), and urge an outright ban of GM foods. Recent food controversies include: (1) the cloning of farm animals in Great Britain (Dyer, 1996; Wilmut et al., 1997); (2) the incidence of Bovine Spongiform Encephalopathy (BSE) or 'mad cow disease' in Great Britain in the early 1990s (Patterson and Painter, 1999; Weihl and Roos, 1999); (3) the advent of the so-called 'terminator seed' technology (Koch, 1998); and (4) the decision by the FDA to classify irradiated and GM foods as organic foods (Cummins, 1997; Weiss, 1998). Others include (5) the case of *Bacillus thuringiensis* (Bt) toxin versus the Monarch butterflies (Hileman, 1999b; Losey et al., 1999; Palevitz, 1999b), (6) the Basmati rice patent controversy, as well as (7) the effect of herbicide and pest resistance on the environment (Longman, 1999).

The critics of genetic engineering are worried and are asking many questions. Should scientists be allowed to cross nature's boundaries by cloning microorganisms, plants, animals, livestock, and possibly humans? (Woodard and Underwood, 1997). Should genetic material be transferred from one organism to another, be it man, animal, plant, bacteria, or viruses? Should humans alter or compete with nature for any reason (Schardt, 1994)? Is this the end of food as we know it (Share, 1994)? Some of these critics include consumer and health advocacy groups, grain importers from Europe, organic farmers, public interest groups, some concerned scientists and environmentalists. Others are politicians, trade protectionists, ethicists, human rights, animal rights and religious rights groups, while the rest are chefs, food producers, and food advocacy groups. These critics believe that applying GM techniques to human food production could have several adverse consequences. For the critics, safety, ethical, religious, and environmental concerns far outweigh the interest in improved food quality, increased food production, and improved agriculture brought about by GM techniques. These critics believe that genetic engineering of foods touches on several issues such as: (1) the right of consumers to know what is in the food they buy; (2) the right of individual countries to set up standards as they deem fit; (3) the relationship between multinational companies, scientists, farmers, and government regulators; (4) the impact of GM crops on biological diversity; (5) the possible negative impact of GM crops on the security of food supply; (6) the possible spread of antibiotic resistance to man and livestock; (7) the possible development of resistance by insects to GM plant toxins; (8) the ecological impact of growing GM foods. These critics, especially those in EU countries, view GM as a suspect new technology that threatens world agriculture, health and ecology, hence they sometimes label GM foods with names such as 'Frankenfood,' 'Farmageddon,' etc. Resistance to GM foods in Great Britain grew because of the 'mad cow disease' as well as several *Salmonella* outbreaks which have eroded public confidence in food safety regulations. This resistance was heightened by a controversial study in 1999 by a food scientist, Arpad Pusztai, of the Rowett Research Institute in Aberdeen, Scotland; the study claimed that rats' growth were stunted when GM potatoes were fed to the animals (Enserink, 1999b; Ewen and Pusztai, 1999; Rhodes, 1999).

Supporters of genetic engineering of foods, including members of private industries, food technologists, food processors, distributors, retailers, scientists, nutritionists, some consumers, U.S. farmers, and regulatory agencies, advocates for the world's poor and hungry people, as well as proponents of the Green Revolution, think that because genetic engineering techniques have recently become simplified, the methods can be applied to the large-scale production of food and drugs needed by the ever-growing world population. In addition, genetic engineering may lead to faster growing, disease-, weather-, and pest-resistant crops, herbicide tolerant crops, as well as tastier, safer, more convenient, more nutritious, longer-lasting and health-enhancing foods (BIO, 1998; Day, 1996). Proponents of GM foods believe that prospects for benefiting humanity are almost limitless, and that GM can potentially solve critical problems of world agriculture, health, and ecology. They also believe that opposition to GM foods stems from irrational fears and trade protectionism rather than from realistic concerns for the health, environment, and livelihoods of farmers in developing countries. In fact they accuse opponents of GM foods of basing their argument on politics rather than on sound science. It is ironic that medical biotechnology, which accounts for most of the products of genetic engineering, encounters the least controversy while food biotechnology shows the opposite trend. It is also ironic that the GM food technology which originated from Europe has the stiffest opposition in EU countries, especially Great Britain.

3. History of genetic engineering of food

Genetic engineering of food has been with man since time immemorial. Forms of genetic engineering have been practiced by resourceful farmers by breeding plants and animals to emphasize certain attributes, by gathering and planting the seeds of fatter grains, by selecting meatier and hardier animals for breeding, and by cross-fertilizing different species of plants to create new varieties that exhibit the most desirable characteristics of the parent plants (Schardt, 1994). Traditional plant breeding is, however, random and imprecise, and it can take up to 20 years to produce a commercially valuable new variety. This approach is limited by the fact that breeders can only cross a plant with its close relative. Direct application of genetic engineering techniques including traditional breeding started in the 1960s, has continued in the 1990s, and will perhaps proceed into the 21st century (Phillips, 1994).

Genetically engineered foods first appeared in the food market in the 1960s. In 1967, a new variety of potato called Lenape potato was bred for its high solids content which made it useful for making potato chips. After two years, this new potato variety developed a toxin called solanine. Consequently it was withdrawn from the market by the USDA. The development of this toxin in the new potato showed that genetic alteration of plants or even animals might have unexpected effects (McMillan and Thompson, 1979). Nonetheless, plant breeding has a good safety record and has succeeded in removing toxic elements in a number of common foods.

In 1979, at Cornell University, New York, scientists started the first study on recombinant bovine somatotropin (rBST), a synthetic growth hormone for cows. This hormone, when injected to dairy cows, increased their milk producing capacity.

In the 1980s, researchers in the United States (Monsanto Corporation), West Germany (Max Planck Institute for Plant Breeding), and Belgium found a method of creating transgenic plants by using a pathogenic bacterium, *Agrobacterium tumefaciens* (Fraley et al., 1983; Zambrynsky et al., 1983). The researchers introduced new genes into plants with the help of this bacterium and also introduced a marker gene for kanamycin resistance to select the transformed cells (Bevan et al., 1983; Herrera-Estrella et al, 1983). This technique has become useful and has been used to introduce dozens of other traits into plants (Hinchee et al., 1988) including the slow ripening characteristic of tomatoes.

The period from 1983 to 1989 was the time for development of more sophisticated recombinant DNA techniques that allowed for genetic transformation of plants and animals. During this period, the U.S. government gave approval for use of rBST in dairy cows. The U.S. government also gave the framework for regulating biotechnology to three regulating agencies, namely, the Food and Drug Administration (FDA), the US Department of Agriculture (USDA), and the Environmental Protection Agency (EPA) (Phillips, 1994).

In the 1990s, the first genetically engineered foods were made available to the public. In 1990, Pfizer Corporation's genetically engineered form of rennet used in making cheese was approved, but it received little public attention. The American Medical Association (AMA) and the National Institute of Health (NIH) independently concluded that meat and milk from cows treated with rBST were as safe as untreated ones. A year later, the American Pediatric Association approved rBST. In 1993, the FDA gave approval for rBST in dairy cows. Researchers at Cornell University have also produced rPST (recombinant porcine somatotropin) used in pigs to produce lean pork. This rPST also led to reduced feed intake but more meat production in pigs. In 1994, FDA finally gave approval for Calgene Corporation's Flavr Savr Tomato, the first genetically engineered whole food approved for the market (Thayer, 1994).

The cloning of farm animals in Scotland from fetal and embryonic cells (Dyer, 1996), and surprisingly, from adult mammalian cells (Wilmut et al., 1997; Wise, 1997), the introduction of the so-called 'terminator seeds' (Koch, 1998), the use of the 'gene gun' or 'biolistic gun' technique (instead of *Agrobacterium*) to shoot foreign genes directly into chromosomes of some hardy crops (Lesney, 1999), as well as the production of herbicide and pest resistant plants by some seed companies (Liu, 1999) are among the latest development in the field.

4. Potential risks of genetically modified foods

The critics of genetic engineering of foods have concerns, not only for safety, allergenicity, toxicity, carcinogenicity, and altered nutritional quality of foods, but also for the environment (Table 2). They fear that gene transfer techniques can result in some mistakes as these methods, like other human efforts, are far from foolproof. According to Phillips (1994), the new genetic material sometimes might not be successfully transferred to the target cells, or might

Table 2
Potential risks or concerns from use of GM foods

Risks or concerns	References
Alteration in nutritional quality of foods	Phillips, 1994; Young and Lewis, 1995
Antibiotic resistance	Hileman, 1999a; Phillips, 1994
Potential toxicity from GM foods	Phillips, 1994
Potential allergenicity from GM foods	Billings, 1999; Coleman, 1996; Nordlee et al., 1996
Unintentional gene transfer to wild plants	Hileman, 1999a; Kaiser, 1996; Rissler and Mellon, 1993, 1996
Possible creation of new viruses and toxins	Phillips, 1994
Limited access to seeds through patenting of GM food plants	Lustgarden, 1994b; Koch, 1998
Threat to crop genetic diversity	Koch, 1998; Phillips, 1994
Religious/cultural/ethical concerns	Crist, 1996; Robinson, 1997; Thompson, 1997
Concerns for lack of labeling	Federal Register, 1992; Hoef et al., 1998
Concerns of animal rights group	Kaiser, 1999; Koenig, 1999
Concerns of organic and traditional farmers	Koch, 1998
Fear of the unknown	Koch, 1998; Longman, 1999

be transferred onto a wrong spot on the DNA chain of the target organism, or the new gene may inadvertently activate a nearby gene that is normally inactive, or it may change or suppress the function of a different gene, causing unexpected mutations to occur, thereby making the resulting plant toxic, infertile, or unsuitable. The following are some of the potential risks.

4.1. Alteration in nutritional quality of foods

Foreign genes might alter nutritional value of foods in unpredictable ways by decreasing levels of some nutrients while increasing levels of others. This will cause a difference between the traditional strain and the GM-counterpart. In addition there is little information yet regarding the effect of the changes in nutrient composition of food plants and animals on: (1) nutrient interactions, (2) nutrient-gene interaction, (3) nutrient bioavailability, (4) nutrient potency, and (5) nutrient metabolism. There is also a paucity of information on situations in which these altered nutrients are involved in the complex regulation of gene expression (Young and Lewis, 1995). The changes in food and diet through biotechnology occur at a pace far greater than the scientists' ability to predict the significance of the changes on pediatric nutrition. Critics therefore advise that caution should be exercised regarding use of GM food products in infant foods.

4.2. Antibiotic resistance

In genetic engineering, marker genes bearing antibiotic resistance are often used in the target organism. There is a concern that deliberately breeding antibiotic resistance into widely consumed crops may have unintended consequences for the environment as well as for humans and animals consuming the crops (Phillips, 1994). According to a report from the British Medical Association, antibiotic resistant marker genes inserted into certain crops could be transferred to disease-causing microbes in the gut of humans or animals consuming GM foods. This could result in antibiotic resistant microbes in the population, and contribute to the growing public health problem of antibiotic resistance (Bettelheim, 1999; Hileman, 1999a).

4.3. Potential toxicity

Genetic modification could inadvertently enhance natural plant toxins by switching on a gene that has both the desired effect and capacity to pump out a poison. Genes for some natural toxins such as protease inhibitors in legumes, cyanogens in cassava and lima beans, goitrogens in canola species, and pressor amines in bananas and plantains, may be turned on and lead to an increase in levels of these toxins which can pose a hazard to the consumers of these crops. Consumer advocates, especially those in EU countries, say that there is not enough research done to prove that GM crops are safe to eat. These crops could carry potential toxins. Concerns for safety of GM foods have stirred the most passionate debate among the public, and has led to boycotts, bans and protests as evidenced in the recent World Trade Organization (WTO) meeting in Seattle, Washington, in late November 1999 as well as the USDA and Industry discussions in Chicago in early November 1999.

4.4. Potential allergenicity from GM foods

Genetic modification of food plants could transfer allergenic properties of the donor source into the recipient plant or animal**.** In addition, many genetically engineered foods use microorganisms as donors whose allergenic potential are either unknown or untested. As well, genes from non-food sources and new gene combinations could trigger allergic reactions in some people, or exacerbate existing ones. GM foods containing known allergens (like peanuts, wheat, egg, milk, tree nuts, legumes, crustacea, fish and shellfish proteins) could spark allergic reactions in susceptible consumers.

The Pure Food Campaign, a food advocacy group based in Washington, DC, is concerned not only about nutrient loss and introduction of new toxins but also about allergens and potential side effects (Billings, 1999; Coleman, 1996; Schardt, 1994). Pioneer Hi-bred International (a seed company now owned by Dupont) incorporated Brazil nut genes into soybeans to increase the protein content of its animal feed. This gene modification caused allergic reactions in consumers who were allergic to Brazil nut, so this product was voluntarily recalled (Nordlee et al., 1996).

The FDA does require food companies to demonstrate through scientific data that potential allergens are not contained in any of their GM foods, and if they are, the FDA requires a label indicating that fact. Although the regulatory agencies, FDA and EPA, require biotech companies to report presence of problem proteins in their modified foods, there is a concern that unknown allergens can slip through the system.

4.5. Environmental concerns

4.5.1. Unintentional gene transfer to wild plants

Environmentalists are concerned that transgenic crops will present environmental risks when they are widely cultivated (Kaiser, 1996). Genetically modified crops having herbicide and insect resistance could cross-pollinate with wild species, and unintentionally create hard-to-eradicate super-weeds especially in small farm fields surrounded by wild plants. This unintentional gene transfer, although hard to substantiate, can have consequences that are not yet known (Hileman, 1999a). These super-weeds can become invasive plants with potential to lower crop yields and disrupt natural ecosystems. Transgenic crops could also become weeds requiring expensive and environmentally dangerous chemical control programs (Rissler and Mellon, 1993, 1996). Opponents of GM crops want regulations to demand proper studies to assess the risks of GM crops on the environment. They believe that Bt toxin, for example, can threaten beneficial insects by entering the food chain.

4.5.2. Possible creation of new viruses and toxins

Plants engineered to contain virus particles as part of a strategy to enhance resistance could facilitate the creation of new viruses in the environment (Phillips, 1994). Plants engineered to express potentially toxic substances such as drugs and pesticides will present risks to other organisms that are not intended as targets.

4.6. Limited access to seeds through patenting of GM food plants

Some critics of genetic modification argue that patenting which allows corporations to have monopoly control of genetically altered plants or animals violates the sanctity of life (Dickson, 1999; Lustgarden, 1994b). Critics also oppose the fact that seeds which have been largely known as commodity products are now regarded as proprietary products because of genetic modification. Many critics view the ‘terminator gene’ technology as a monopoly and anti-competition. Terminator gene technology produces sterile seeds which will never germinate when planted (Koch, 1998). It forces farmers to buy new seeds each year from multinational companies so that farmers become dependent on the multinationals instead of sowing seeds from the previous years' harvest. It is argued that this would destroy traditional farming practices. There have been several protests against the terminator gene technology in many developing countries, especially India.

4.7. Threat to crop genetic diversity

Critics of genetic modification of foods fear that commercialization of transgenic crops will pose a new threat to crop genetic diversity already endangered by current agricultural practices that favor the worldwide adoption of a few crop varieties (Phillips, 1994).

Genetic modification also reduces bio-diversity of the world's food supply through the use of 'terminator' seed technology which produces sterile seeds and controls seed supply especially in developing countries (Koch, 1998).

4.8. Religious, cultural, and ethical concerns

Religious concerns are also voiced as some of the reasons for opposing genetic engineering of foods, while some people object to bio-engineered foods for personal, ethical, cultural, and esthetic reasons, as well as infringement on consumer choice, and inability to distinguish GM foods from non-GM counterparts (Robinson, 1997; Thompson, 1997). For example, Jews and Muslims may be aversive to grains that contain pig genes, and usually insist on Kosher and Halal foods whose purity can be documented. Vegetarians may similarly object to vegetables and fruits that contain any animal genes (Crist, 1996). Some people fear eating plant foods containing human genes.

4.9. Concerns for lack of labeling GM foods

Many critics are concerned that GM foods are not labeled. They insist that labeling can help the consumer trace unintended consequences to a certain consumed GM food. In the United States, the safety and wholesomeness of food supply (except meat and poultry) is regulated by the FDA, and this agency regulates biotech-derived products under its official policy on foods derived from new plant varieties (Federal Register, 1992). With regards to these new plant foods, a summary information on safety and nutritional assessment shall be provided to the FDA, while a scientific presentation of data shall be made informally to the FDA scientists (Maryanski, 1995). All these notification processes will enable the FDA to be updated on recent developments in the technology and facilitate future resolution of safety or regulatory issues that may arise. This policy applies whether the new plant arose from genetic engineering or by conventional breeding methods. This policy determines (1) whether consultation with FDA is mandated; (2) when labeling is required; and (3) what information should be conveyed in the labels. Most plant breeders subject their products to safety and quality control practices such as chemical, physical and visual analyses as well as sensory (taste) testing, and these practices are acceptable to the FDA. Further testing is required if the product's history of use, composition, and characteristics warrant it. The FDA and USDA have been staunch defenders of genetically engineered foods and high chemical input agriculture, and both agencies are strong opponents of labeling of GM foods. Some international organizations also support GM foods provided the safety of the foods are assured (FAO/WHO, 1991; OECD, 1993). In addition, the FDA has concluded that genetically altered seeds and products are additives that do not affect either safety or nutritional quality of food (Kessler et al., 1992; Ronk et al., 1990). The FDA requires a label if an addition poses some identifiable threat such as an allergic reaction or leads to a dramatic change in nutrient content. However, others feel that labeling will benefit both the consumer and manufacturers for the following reasons: (1) It will enable consumers who prefer specially engineered GM foods (e.g. those with health enhancing properties) to get them while enabling others to avoid certain foods for ethical, cultural, or religious reasons. (2) Labeling would enable manufacturers to emphasize the improved quality of their product, for example, improved taste, longer shelf-life, and insect resistance, and these would be good selling points that could appeal to consumers. (3) Lack of labeling would deny producers a chance to build brand identity.

Regulatory agencies oppose labeling for the following reasons. First, labeling of GM foods would stigmatize biotech products and scare away shoppers, and unduly alarm consumers about potential safety risks thereby putting some retailers out of business; biotech products should therefore not be singled out for special regulatory treatment unless there is a significant difference in composition, a safety problem, or missing material information. When biotech foods are labeled differently from their traditional counterparts, it will have the unintended and unfortunate consequence of confusing consumers or misleading them into thinking that biotech products have different effects. Second, labeling could also be difficult to implement because the label has to be maintained throughout the food chain, no matter how many times the GM food is used as an ingredient, food, or feed. This could create a logistical nightmare. Third, labeling GM foods may be expensive, and the cost of labeling will be passed on to the consumer. However, some people are optimistic that a technology that can easily distinguish GM foods from non-GM ones would soon be developed, thereby making labeling an easy task (Hoef et al., 1998).

4.10. Concerns of animal rights groups and organic farmers

Animal rights groups are among the loudest opponents of genetic engineering. They strongly oppose any form of cloning or genetic engineering involving animals, or use of animals in research, and have sometimes resorted to vandalizing animal research facilities (Kaiser, 1999; Koenig, 1999).

Organic farmers fear that GM foods would obscure organic foods because of lack of labeling, and they feel that the biotech revolution could make it difficult for people to locate non-GM crops. Organic foods are generally defined by consumers as those foods produced naturally without toxic chemicals, drugs, pesticides, herbicides, synthetic fertilizers, hormones, GM products, sewage sludge, irradiation or factory farm techniques. There is a concern that organic crops might be contaminated through cross breeding of herbicide resistant plants with wild relatives, or through cross pollination with GM crops in neighboring farms, thereby creating ‘monster weeds’ resistant to natural pesticides normally used by organic farmers. There is also a fear that pests resistant to Bt toxin will be produced (Koch, 1998).

4.11. Fear of the unknown

Consumers also have a genuine ‘fear of the unknown’ in that deadly microorganisms or super plants might be released during field testing or field trials, and accidents in biotech labs might lead to release of toxic agents, poisons, or biological toxins which will threaten human and animal populations. Critics, especially members of Alliance for Bio-ethics, The Pure Food Campaign, the Green Peace Movement, the Sierra Club, International Federation of Organic Agricultural Movements, Mothers For Natural Law, and Council for Responsible Genetics, are angry at the FDA for opposing labeling of GM foods, and accuse the FDA of ignoring the uncertainty created by genetic changes, thereby robbing consumers of the right to know what is in their food. They maintain that some of these GM foods had never before existed in nature, and that consuming them without prior testing and labeling would reduce consumers into mere guinea pigs in a colossal biological experiment. Moreover, the science of genetic engineering is relatively young, less than 50 years old, and nobody knows the consequences of these genetic alterations in the future. This fear of the unknown has made some baby food manufacturers (such as Gerber and Heinz) to refrain from using GM crops in baby foods (Enserink, 1999a,b). For similar reasons, some breweries in Japan and tortilla chip factories in Mexico are hesitant about using GM corn in their products. Some traditional family farmers also fear that biotech farming can someday drive them out of business as farmers would no longer have control over the farming business. There is a fear that wealthier nations will no longer choose to import vanilla, cocoa, coffee, Basmati rice, and other tropical crops from poorer Latin American, African, and Asian countries. The livelihood of tropical farming families and agricultural workers would be in jeopardy, and this would lead to a dislocation of the world's poorest people (Longman, 1999).

This fear of the unknown is also at the root of trade disputes between some European Union countries and the United States. Many European grain importers, especially soybean and corn traders, are threatening to boycott U.S. grains if such grains are not labeled. The Europeans see GM as a pure risk with no benefit, or believe that EU countries lack a fully established united regulatory philosophy or system for GM products (Gaskell et al., 1999). This consumer resistance to GM foods escalated to such a point that EU countries placed a moratorium on new approvals for GM crops (Hileman, 1999a). Continued resistance to GM foods will lead to loss of millions of dollars in U.S. grain exports. The risk of not being able to sell GM crops may hurt U.S. farmers financially, and this may slow the genetic revolution.

Table 3
Consumer willingness to purchase produce developed by biotechnology

Country	USA	USA	USA	Japan	Japan
Year	1995	1996	1997	1995	1998
Number	$n = 1012$	$n = 1004$	$n = 1018$	$n = 1004$	$n = 1002$
Willingness to purchase type of produce (%)					
Insect protected					
Very likely	31	29	43	5	8
Somewhat likely	42	48	34	64	63
Not too likely	15	13	14	28	25
Not at all likely	9	9	9	3	4
Better tasting or fresher					
Very likely	20	17	22	4	8
Somewhat likely	42	41	40	59	62
Not so likely	23	27	20	34	26
Not at all likely	14	14	18	3	4

Source: Hoban, 1999.

On the contrary, many people in the United States and Japan (Table 3) believe that they are sufficiently informed about the new technology and GM foods, and accept such foods without worries as long as the regulatory agencies give scientific assurance for the safety, wholesomeness and nutritional quality of the foods (Hoban, 1999). In addition, Canada, Australia, Brazil, and Argentina have accepted agricultural biotech crops according to the International Service for the Acquisition of Agribiotech Applications (ISAAA), while a positive reaction is expected in China (Thayer, 1999). However, there is a concern that continued opposition of GM foods abroad may soon influence acceptability of GM food in the United States.

5. Benefits of GM foods

Supporters of the genetic engineering of foods cite increased year-round food availability, improved nutritional quality, and extended shelf-life as some of the reasons (Table 4) why they encourage the new science which will benefit consumers, farmers, and the environment. Moreover, they believe that it will lead to a general improvement in agriculture and food, and will provide healthier, cheaper, more stable, nutritious, better tasting, and safer foods.

Future applications of this science will increase plant resistance to pests, insects, disease herbicide, weather, and other environmental stresses. Many genetically engineered plants and even animals will grow faster and reproduce faster. Because scientists are able to intro-

Table 4
Potential benefits from GM technology

Benefits of GM technology	References
Increase in food availability	Jackson, 1991; Moffat, 1992; Rudnitsky, 1996; Schardt, 1994
Improved shelf-life and organoleptic quality of foods	BIO, 1998; Thayer, 1994; Walters, 1994
Improvement in nutritional quality and health benefits	Ames, 1998; BIO, 1998; Clinton, 1998; Elliot, 1999; Nguyen and Schwartz, 1999; Smaglik, 1999
Improved protein quality	BIO, 1998; De Lumen et al., 1997; Haumen, 1997; Kitamura, 1995; Roller and Hallander, 1998
Increase in food carbohydrate content	BIO, 1998; Liu, 1999; Starke et al., 1996
Improvement in quantity and quality of meat, milk and livestock	Bishop, 1996; Dalrymple, 1998; Rohricht, 1999; Wilmut et al., 1997
Increased crop yield	BIO, 1998; Hadfield, 1996; Jackson, 1991; Jacoby, 1999; Paoletti and Pimental, 1996; Wood, 1995
Manufacture of edible vaccines and drugs	Ames, 1998; Daie and Belanger, 1993; Hsu, 1999a,b; Kiernan, 1996; Lesney, 1999; Oldham, 1996; Sloan, 1999
Biological defense against diseases, stresses, pests, weeds, herbicides, and viruses	BIO, 1998; Hileman, 1999a,b,c; Jacoby, 1999; Liu, 1999; Losey et al., 1999; Thayer, 1999; Wilkinson, 1997; Wood, 1995
Bioremediation	Howe, 1997; Gray, 1998; Paoletti and Pimental, 1996
Positive effect on farming/food product	Thayer, 1999
Protection of the environment	BIO, 1998
GM crops function as bio-factories and source of industrial raw materials	Block and Langseth, 1994; Del Vechio, 1996; Goddijn and Pen, 1995; Hercberg et al., 1998; Hsu, 1999b; Moffat, 1992; Sloan, 1999
Wealth/job creation	Alliance For Better Foods, 1999; Thayer, 1999

duce genetic traits into organisms with better precision, mistakes are less likely to occur (Schardt, 1994). Plants having new traits with specific benefits will be genetically produced in a selective and controlled manner. Supporters of GM foods believe that potential risks of GM technology are hypothetical, though it is also too early to tell if GM technology is beneficial in all plants. The potential benefits of GM foods are discussed below.

5.1. Improvement in fruit and vegetable shelf-life and organoleptic quality

GM has led to improved shelf-life and organoleptic quality in certain crops. The Flavr Savr tomato is the first genetically engineered crop and whole food approved by the FDA (Redenbaugh et al., 1993; Thayer, 1994; Walters, 1994). Flavr Savr tomato was produced by Calgene Corporation. It was bio-engineered to ripen on the vine, and have a longer shelf-life by having delayed ripening, softening, and rotting processes. Delayed ripening of fruits and vegetables (via ethylene control technology and suppression of cell wall destroying enzyme, polygalacturonase) leads to superior flavor, color, texture, longer shelf-life and better shipping and handling properties (BIO, 1998; Thayer, 1994). Recently, sweet-tasting, firmer, seedless peppers and tomatoes have been produced. The slow or delayed ripening characteristics could also be replicated in other crops like raspberry, strawberry, and pineapple, and can extend the crop's shelf-life. Extending a product's shelf-life not only benefits the producer and seller, but also enables the consumer to utilize the product for a longer time before it spoils. Such fruits and vegetables can remain fresh longer, and can better withstand handling, shipping, and storage. Good shipping and handling properties will also benefit farmers and consumers in developing countries where refrigeration is unreliable and expensive, and transportation network rudimentary (Phillips, 1994).

5.2. Improved nutritional quality and health benefits

Genetically modified crops have tailored and added value features such as nutrients and health benefits. Bovine growth hormone enhances milk production in cows. Pigs can also be treated with a hormone called recombinant porcine somatotropin (rPST), a growth hormone that increases meat production in pigs, and reduces the amount of fat thereby producing low-fat pork. Soya bean could also be bio-engineered to form a more nutritious and flavorful crop. Genetic engineering can be used to increase levels in food of minerals and naturally occurring anti-oxidant vitamins (carotenoids, flavonoids, vitamins A, C, and E), compounds that can slow or shut down biological oxidation, a damaging chemical reaction, that appears to promote the development of some cancers, heart disease, and blindness (Ames, 1998; Smaglik, 1999). Increased levels of anti-oxidants in food can lead to a reduction in the rates at which certain cancers and other chronic diseases are found in the population (Table 5), and may also reduce blindness (in the case of vitamin A) (Clinton, 1998; Elliot, 1999; Nguyen and Schwartz, 1999; Phillips, 1994). One important anti-oxidant, lycopene, is abundant in tomatoes, tomato products, and peppers which are currently produced by genetic engineering (BIO, 1998; Clinton, 1998).

Genetic engineering can be used to modify oils to achieve a reduction in the levels of saturated fats and trans fatty acids which are responsible for cholesterol production in the body; GM can also be used to increase the levels of unsaturated fatty acids in some commonly used oils such as canola, soybean, sunflower, and peanuts (Liu and Brown, 1996). Oils low in saturated or trans fatty acids but high in unsaturated fatty acids have important health benefits and cooking performance characteristics. Oils with lower levels of saturated fats and trans fatty acids can withstand higher temperatures used in frying and other processing methods, and have improved temperature stability. Enhanced stability oils are excellent ingredients in cooking, frying, or spray oils without the need for chemical hydrogenation. Other phytochemicals found to have disease fighting nutritional values can also be incorporated into food plants through genetic engineering. Efforts are also underway to produce allergen free rice and peanuts (Alliance for Better Foods, 1999). Biotechnology can be used to introduce or concentrate certain nutrients (such as vitamin A, zinc, iron, iodine) into common dietary staple food plants as a way of delivering optimal levels of key nutrients or fighting some nutritional deficiencies endemic in some regions of the world, including Africa (Wambugu, 1999).

5.3. Improved protein quality through GM

Protein quality of foods and feeds have been improved by genetic engineering (De Lumen et al., 1997; Roller and Hallander, 1998), and there is less risk of allergies from GM foods than in conventional foods (such as Brazil nut and peanut) already in the market or in plants produced by classical breeding methods which introduce potential allergens into the product. Improved protein quality may involve an increase in the essential amino acid content of the crop, for example, an increase in the methionine and lysine content of the protein (Hauman, 1997). It may also involve improvement in the functional properties including organoleptic qualities thereby expanding the use of plant protein in various food systems (Kitamura, 1995). For example, efforts are under way to remove the beany flavor in soybeans through removal of lipoxygenases. Fish, which is a good source of dietary protein, could be produced cheaply through genetic engineering, and these could be conditioned to grow larger in a short period, thus becoming a viable option for aquaculture (Phillips, 1994).

5.4. Increase in carbohydrate content through GM

The carbohydrate content of some food crops has been increased by genetic engineering. Tomatoes with high solids content have been produced and this is useful to food processors

Table 5
Scientific evidence for observed health benefits of antioxidant vitamins in chronic disease

Disease	Vitamin C	Vitamin E	B-Carotene
Cardiovascular disease	+	+++	+
Cancer	++	++	+
Cataracts	++	++	++
Immune function	++	+++	++
Arthritis	+	+	+
Alzheimer's disease	−	++	−

− Little or no evidence of relationship.
+ Some evidence of relationship.
++ Good evidence of relationship.
+++ Excellent evidence of relationship.
Source: Elliot, 1999.

for making tomato paste and sauce. Potato has been genetically modified to have a high solids content, which makes it useful for making French fries (Starke et al., 1996). The high solids potatoes that have been produced by Monsanto Corporation (through insertion of a starch producing gene from bacteria into the potato plant) absorbs less oil during processing into French fries (Liu, 1999). The modification of the potato results in decreases in cooking time, costs and fuel use. This leads to better tasting French fries that provides economic benefit to the food processor (BIO, 1998).

5.5. Improvement in quantity and quality of meat, milk, and livestock production

Genetic engineering, especially animal cloning, could lead to large-scale production of livestock to meet the high demand for meat and protein foods (Bishop, 1996). Countries with the technology for cloning will be able to produce excess livestock which can be exported cheaply to countries with scarce meat and milk supply. Dairy cows can be treated with BST, approved by the FDA since 1993, to enhance milk production in cows. BST is not a human health hazard, and moreover it is a protein which is digested in the gastrointestinal tract, so it is regarded as safe. If excess milk is produced through the use of BST, the milk can be exported to earn foreign exchange. Transgenic animals will be tailored to produce more milk or meat with special qualities, for example, lactose-free milk, low fat milk, low cholesterol meats, low fat meats or meats with special protein and nutrient composition in a cost-effective process (Koch, 1998; Laane and Willis, 1993). Transgenic livestock can also be used to express large quantities of recombinant proteins such as fibrinogen in milk of mammary glands (Dalrymple, 1998; Rohricht, 1999). Transgenic proteins become useful alternatives to blood proteins derived from donated human blood which is feared as a potential source of Human Immunodeficiency Virus (HIV) and Bovine Spongiform Encephalopathy (BSE).

5.6. Increased crop yield

Genetic engineering can be used to increase crop yield and reduce crop loss by making plants tolerant to pests, weeds, herbicides, viruses, insects, salinity, pH, temperature, frost, drought, and weather. Insect resistant fruits such as apples, virus resistant cantaloupes, and cucumbers, and herbicide tolerant corn, tomatoes, potatoes, and soybeans have all been produced (BIO, 1998; Paoletti and Pimental, 1996; Wood, 1995).

Major cereal crops which are annuals may be converted by GM to perennials. This would reduce tillage and erosion, and lead to conservation of water and nutrients (Jackson, 1991). It would also increase crop yield during the year. Such perennial crops would decrease labor costs, improve labor allocation, and generally improve the sustainability of agriculture (Alliance for Better Foods, 1999). Drought resistance in GM crops will reduce water use in agriculture. This will be very useful in some tropical or arid regions where water is scarce. A report in 1996 stated that Japanese researchers had isolated the gene in hot spring bacteria which could make an enzyme for survival in the desert (Hadfield, 1996). If this trait is indeed conferred by a single enzyme, such an enzyme could be engineered into plants thereby enabling them to grow abundantly, help to expand farming, and boost food availability in desert regions. Efforts are underway to genetically produce crops with salt tolerance (Jacoby, 1999), frost and drought resistance, as well as pH tolerance. Increasing a crop's ability to withstand environmental stresses (e.g. extreme pH, salt, pests, heat, etc) will enable growers to farm in those parts of the world currently unsuitable for crop production. This will lead to increased global food production by reducing crop loss and increasing yield, while conserving farmland and reduce pressure on irreplaceable natural resources like the rain forests. It will also provide developing economies with increased employment opportunities and increased productivity.

Genetic modification can also lead to crops with enhanced nitrogen fixation and increased crop yield, which will reduce fertilizer use and cost of production (Jacoby, 1999; Laane and Willis, 1993; Paoletti and Pimental, 1996). By engineering quality traits and new chemistries into plants, agricultural productivity is increased, the need for added farm acreage is reduced, resource consumption is limited, harmful environmental impacts are decreased, while the world's food supply is greatly increased. Increased food production through biotechnology will have a positive global impact by increasing the dietary staples (such as rice, wheat, corn, cassava, potatoes, bananas, beans, cereals, legumes, tubers) of many regions of the world.

5.8. Manufacture of edible vaccines and drugs

Some tropical crops such as banana, which are consumed raw when ripe, have been bioengineered to produce proteins that may be used as vaccines against hepatitis, rabies, dysentry, cholera, diarrhea, or other gut infections prevalent in developing countries (Anon, 1996a, 1998; Ferber, 1999; Kiernan, 1996). These vaccines in edible foods will be beneficial to children in developing countries where such foods are grown and distributed at low cost, and where resources and medical infrastructure for vaccine production are lacking (Mason and Amtzen, 1995).

The nutritionally enhanced crops will help to reduce malnutrition, and will enable developing countries to meet their basic dietary requirements, while boosting disease-fighting and health-promoting foods. Cassava, an important staple food, feeding over 500 million people in many third world countries has recently been bio-engineered to have higher nutrient value and to resist the destructive African cassava mosaic virus and the common mosaic virus (Anon, 1996b). Rice has been genetically modified to make a vitamin A precursor and to accumulate more iron which would prevent infection, blindness, and anemia in people in developing countries (Ferber, 1999).

GM will be used to produce functional foods that will act both as food and drug (Ames, 1998; Sloan, 1999; Smaglik, 1999). For example, potato, banana and tomato, can be engineered to carry vaccines, and broccoli can be modified to be rich in anti-oxidants, while tea can be modified to be rich in flavonoids (Hsu, 1999b; Sloan, 1999). The FDA has already approved 'Benecol' and 'Take Control', two margarines that are supposed to lower cholesterol levels (Ryan, 1999). Some biotech companies have also been able to modify some plants like tobacco to synthesize drugs (Oldham, 1996). Tobacco has also been engineered to produce antibodies useful in man and livestock. Plants containing human antibodies would also carry these materials in their seeds which would provide a stable inexpensive source of genetic material for immunization against common disease. These plant vaccines would have a longer shelf-life and more stable storage capacity (Daie and Belanger, 1993). Some human genes have been inserted into plant chromosomes to yield large quantities of experimental biopharmaceuticals. Tobacco and potato have been engineered to produce human serum albumin. Oilseed rape and *Arabidopsis* have been engineered to yield the human neurotransmitter, Leu-enkephalin and monoclonal antibodies (Lesney, 1999). Work is also going on to produce insulin in plants. The insulin would be ingested by diabetics rather than received through shots. In addition, work is also underway to develop canola oil that could replace whale oil in certain products.

5.9. Environmental benefits of GM

Environmental benefits include protection against insect damage, herbicide tolerance for innovative farming, reduction in the amount of land needed for agriculture, conservation of resources through use of less labor, fuel, fertilizer and water, water quality protection, and protection against plant diseases.

5.9.1. Biological defense against diseases, weeds, pests, herbicides, viruses, and stresses

Many food plants, for example potato, soybean, and corn have been engineered with Bt gene which produces Bt protein (an insecticide). Although Bt is non-toxic to humans, and degrades in the stomach acid, it is toxic to insects such as the European corn borer, cotton bollworms, and potato beetles. This toxic Bt protein eliminates the need for chemical pesticides against insects that transmit viruses and other harmful microbes. Fewer pesticides use also reduces strain on the environment. The snag with Bt insecticide is that it may lead to insects developing resistance to toxins in the field or it may kill non-target insects such as the monarch butterfly (Hileman, 1999b; Losey et al., 1999). In addition, some crop protection companies that produce pesticide chemicals might be financially threatened.

Crops such as tobacco, tomatoes, squash and corn have also been genetically modified to become virus resistant (Liu, 1999; Wood, 1995). In other words, these new crop varieties are essentially ‘vaccinated’ against crop destroying viruses or viral diseases. Efforts are under way to produce fungus resistant crops, reducing the need for these carcinogenic fungicides in the human food chain and in the environment (Paoletti and Pimental, 1996; Thayer, 1999). Some plants are genetically modified to withstand the application of herbicides (Liu, 1999; Wilkinson, 1997), while others are made insect resistant. Such herbicides and insecticides (Table 6) include glyphosate, glufosinate, imidazolinone, sulphonyl urea, bromoxylnil (BXN), some enzyme inhibitors, *Bacillus thuringiensis* toxin, and other toxic proteins (BIO, 1998). In the global agrochemical market (Fig. 1), herbicides account for 50% of sales, insecticides 30%, while fungicides account for 20% (Thayer, 1999). Herbicides are effective against several target weeds while insect resistance is effective in a few crops. Plants modified to resist pests or weed killing herbicides seem to pose minimal risks to human health, however, environmental concerns (although hard to substantiate) are also proving hard to dispel. Genetic modification of plants gives farmers greater flexibility in their pest control strategy, so that weeds are selectively controlled, and environmentally gentler herbicides are used. Genetic modification for herbicide resistance also cuts conventional herbicide use significantly, and allows farmers to use broad-spectrum herbicides against weeds. Sometimes genes are engineered to combine or stack traits for various functions in one seed, for example, herbicide tolerance, insect resistance, and slow ripening. Recently a gene switching technology was developed by Rohm and Haas (a

Table 6
Some herbicides and insecticides developed through the GM technology

Trade name	Common name	Function	Applicable crops	Company
Round Up	Glyphosate	Herbicide	Cotton, soybean, corn	Monsanto
Liberty	Glufosinate	Herbicide	Corn, canola	AgrEvo
Actigard	Acibenzolar-S-Methyl (benzothiadiazole)	Antifungal, antibacterial	Several crops	Novartis
MAC (Molt Accelerating Compound)	(Diacyl hydrazine)	Insecticide	Several crops	Rohn & Haas
Touchdown	Trimethyl sulfonium salt of glyphosate	Herbicide	Several crops	Zenecca
Acuron	Protoporphyrin Oxidase Inhibitor	Insecticide	Several crops	Norvatis
Bollgard	Protein	Insecticide	Corn	Monsanto
Bt toxin	Bacillus thuringiensis protein	Insecticide	Corn	Monsanto
Photorharbdus	Photoharbdus	Insecticide	Several crops	Dow
Bromoxynil	Bromoxynil	Herbicide	Cotton, canola	Rhone-Pulenc
Sulfonyl urea	Sulfonyl urea	Herbicide	Several crops	Dupont
DeKalb™	Toxic plant protein	Insecticide	Corn	DeKalb Genetics Corp.
Star™	Imidazolinone	Herbicide	Corn, canola	American Cyanamid

Source: BIO, 1998; Thayer, 1999.

food /chemical company); the gene can be activated in a plant to simultaneously improve pest management, ripening, and other genetically expressed traits (Thayer, 1999).

5.9.2. Positive impact of GM on farming and food production

Genetic modification has a positive impact on farming and food production. Through innovations in chemistry, biotechnology, and crop science, agricultural productivity is increased. GM also increases fertilizer efficiency, improves crop production efficiency, and increases the world's food supply by creating environmentally friendlier crops. Biotech crops are now improved to draw more nitrogen directly from the soil thereby reducing the need for chemical fertilizers and less damage from fertilizer run off. Waste fertilizer, which usually evaporates or washes into waterways and estuaries, can endanger the environment.

Through GM, farmers have greater flexibility and choices in pest management. Herbicide tolerant crops promote conservation tillage, preserve topsoil, and protect water quality. Farming of

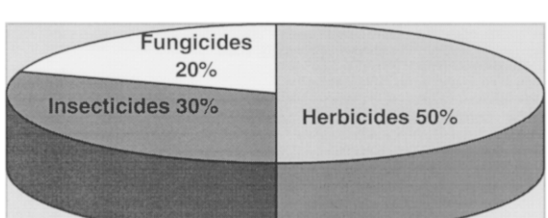

Fig. 1. Global agrochemical sales in 1998.

herbicide tolerant crops leads to increased productivity and cost reduction, due to reduction in the use of agro-chemicals, thereby making farming a more profitable and rewarding venture for farmers. Farmers are therefore showing interest in transgenic crops because of their benefits. In 1998 (Fig. 2), farmers planted transgenic crops on over 70 million acres of land (Thayer, 1999), and growth in transgenic farming is expected to triple in the next five years according to the International Service for the Acquisition of Agribiotech Applications. Sales of transgenic seeds will reach several billions of dollars in the next 10 years. Through GM, some crops are protected from disease by being treated with chemicals that function like vaccines. Disease protection is evident in rice, sweet potato, and cassava, important tropical crops in Africa and Asia. Agricultural biotechnology will be particularly useful in land conservation in developing countries where valuable temperate and tropical forest lands are being converted to farmlands at an alarming rate. The fast disappearance of the environmentally sensitive tropical forest has serious global implications.

5.9.3. GM plants can remove industrial waste and improve recycling of toxic chemicals

Genetic modification of plants has been useful in bio-remediation. Some plants have been specially bio-engineered to enable them remove toxic waste from the environment. Several researchers have reported encouraging results using plants like mustard greens, alfalfa, river reeds, poplar trees, and special weeds to clean up the ravages of industries, agriculture, and petroleum production (Contreras et al., 1991; Howe, 1997; Paoletti and Pimental, 1996). In some cases, plants can digest the poisons, and convert them to inert compounds (Gray, 1998).

5.10. GM products useful in organ transplants and in the treatment of human diseases

Because cloned animals model many human diseases, scientists can effectively study human diseases such as cystic fibrosis, for which there is currently no cure. Cloned animals may be used to produce pharmacologically useful proteins such as clotting factor, used by hemophiliacs, or insulin used by diabetics. Some farm animals, for example, goats, pigs and sheep, may be cloned, and used to grow organs such as hearts, livers, kidneys and fetal cells suitable for transplant into humans. This could end the long waiting period for organ transplants by seriously ill patients (Sinha, 1999).

5.11. GM crops act as bio-factories and yield raw materials for industrial uses

By combining plant breeding and genetics with cell and molecular biology techniques, crop plants are now made to act as bio-factories (Goddijn and Pen, 1995; Hsu, 1999b; Moffat, 1992; Palevitz, 1999a). Some GM crops are specially designed to produce food enzymes, vitamins, monoclonal antibodies, vaccines, anticancer compounds, antioxidants, plastics, fibers, polyesters, opiates, interferon, human blood proteins, and carotenoids. GM can be used to produce food ingredients like proteins, enzymes, stabilizers, thickeners, emulsifiers, sweeteners, preservatives, colorants, and flavors used in the food industries (Laane and Willis, 1993). Microorganisms used in food processing and pathogen detection are being produced by GM. Food enzymes like chymosin used in cheese production can be cheaply produced through GM. Common crops like tobacco, corn, potato, and cotton can be genetically modified to manufacture various materials such as human proteins or enzymes as well as natural polymers (such as polyesters). In future, some plants can be bioengineered to produce environmentally friendly non-petroleum based fuel alternatives. Production of these substances through GM technology is more advantageous than through the traditional process because the new technology produces larger amounts of the de-

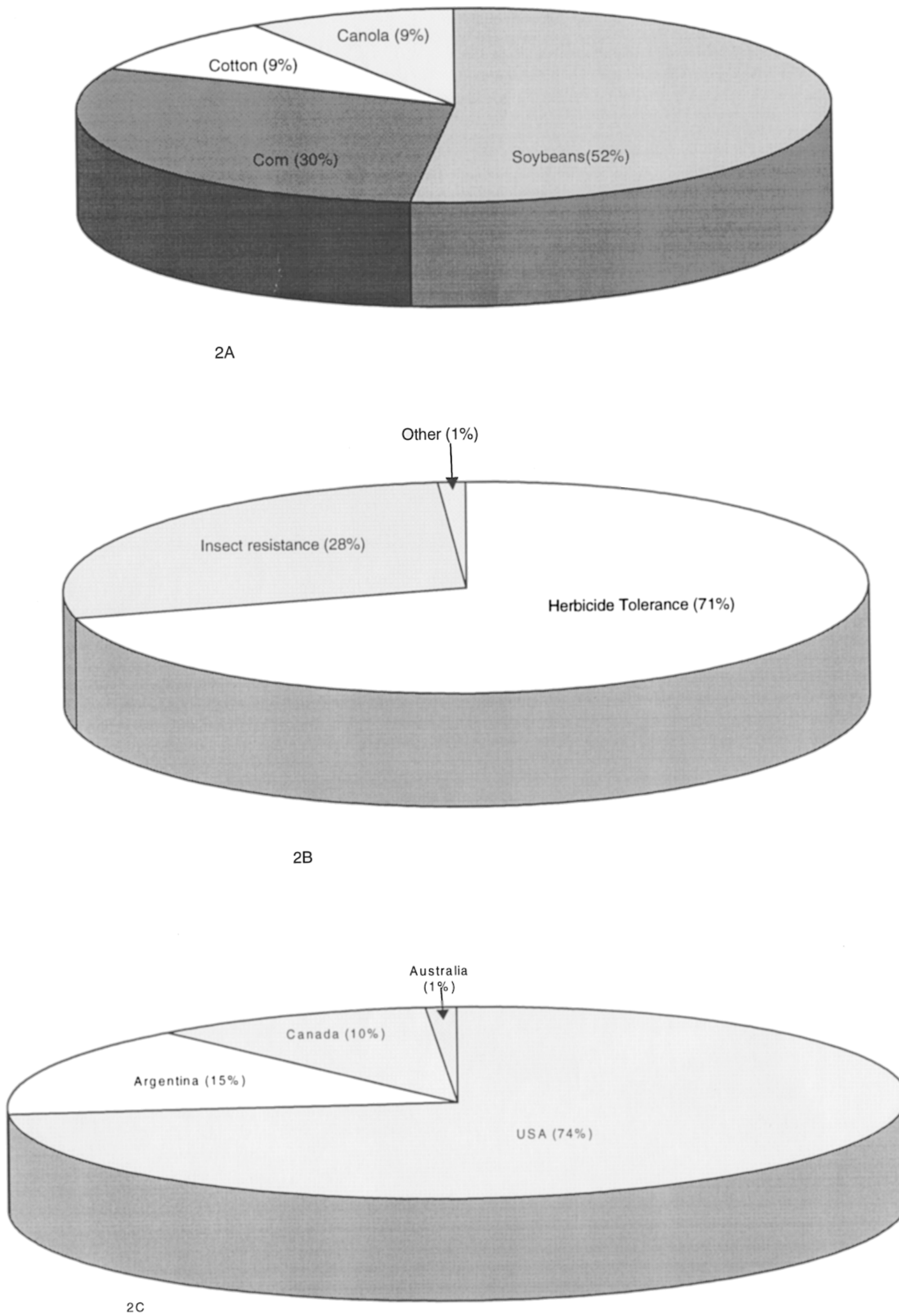

Fig. 2. Percent acreage planted with ag. biotech plants (Source: Thayer, 1999). (A) By major crops, (B) by genetic trait, (C) by geographic region.

sired product, at less cost and in a more convenient form for storage and transport. The amylase produced from tobacco, for example, is produced in such a large quantity that it can be marketed to food industries that use it in the manufacture of foods such as bread and low calorie beer, and in the clarification of wines and fruit juices. Some genetically engineered and naturally occurring foods with special health benefits are now called nutraceuticals (a cross between nutritious foods and pharmaceuticals). Such foods are designed to contain, not only nutrients, but also other compounds (such as antioxidants, low cholesterol oils or poly-unsaturated fatty acid oils, flavonoids, fructans, vitamins, carotenes, lycopenes, phyto-chemicals, pharmaceuticals) that have disease-preventing, disease-fighting, sympton-reducing, and performance-enhancing capabilities. Other neutraceuticals are designed to slow down the aging process by suppressing oxidative processes (Block and Langseth, 1994; Hercberg et al., 1998). These foods acting as medicines will be well patronized in the 21st century (Sloan, 1999; Smaglik, 1999).

Genetic modification leads to oilseed crops with unusual fatty acids such as short-, medium-, and long-chain fatty acids, and those with double bonds at unusual positions, or those that carry hydoxyl or epoxy groups. Oils having unusual fatty acids are useful as industrial oils which are more expensive than regular oils. Such oils can be used for soaps, detergents, cocoa butter, and replacement fats (Del Vechio, 1996; Kridl and Shewmaker, 1996; Liu, 1999).

Major companies involved in developing plant genetic engineering and GM crops include Monsanto, Norvatis, Dupont, and AgrEvo (Table 7). These main players are the biggest of the chemical companies that have expanded into the life sciences. Many of them have made the transition from plant protection to plant production. These life sciences conglomerates have combined the benefits of food, pharmaceutical, and biotechnology industries (Table 8).

6. Future considerations

Although genetic modification of foods is important and beneficial, it should be adopted under conditions that avoid potential risks. Time and effort must be devoted to field testing before the re-

Table 7
Major players in the GM technology arena

Company	1998 Sales (millions of US $ dollars)
Novartis	5010
Monsanto	4030
Dupont[a]	3156
Zeneca	2798
Dow Chemical	2352
AgrEvo[b]	2330
Bayer	2200
American Cyanamid	2190
Rhone-Poulenc[c]	2066
BASF	1880

[a] Includes nutrition but not proposed acquisition of Pioneer Hi-bred.
[b] Joint venture between Hoechst and Scherring.
[c] Business to be merged with AgrEvo to become Aventis Crop Science.
Source: Thayer, 1999 (from Company Reports).

Table 8
Major companies tap technologies through recent alliances

Company	Partner	Technology basis of collaboration
AgrEvo[a]	Gene Logic	Genomics for crops/crop protection
	Kimeragen	Gene modification
	Lynx Therapeutics	Genetics for crop science
American Cyanamid[b]	Acacia Biosciences	Compounds for agrochemicals
	AgriPro Seeds	Herbicide tolerant wheat
	Zeneca Seeds	Transgenic canola
BASF	Metanomics[c]	Functional plant genomics
	SunGene[d]	Testing genes in crops
Bayer	Exelixis Pharmaceuticals	Screening targets for agrochemicals
	Lion Bioscience	Genomics for crop protection products
	Oxford Assymetry	Compounds for agrochemicals
	Paradigm Genetics	Screening targets for herbicides
Dow Chemical	Biosource Technologies	Functional genomics for crop traits
	Demegen	Technology to increase protein content
	Oxford Asymmetry	Compounds for agrochemicals
	Performance Plants	Gene technology to increase yield/content
	Proteome Systems	Protein production in plants
	Ribozyme Pharmaceuticals	Technology to modify oil/starch content
	SemBioSys Genetics	Commercialize proteins produced in plants
DuPont	CuraGen	Genomics for crop protection products
	3-D Pharmaceuticals	Compounds for agrochemical targets
	Lynx Therapeutics	Genetics for crops/crop protection
FMC	Xenova	Compounds for agrochemicals
Monsanto	ArQule	Compound libraries for agrochemicals
	GeneTrace	Genomics for crops
	Incyte Pharmaceuticals	Plant, bacterial, fungal genomics
	Mendel Biotechnology	Functional genomics in plants
	Cereon Genomics[e]	Plant genomics
Novartis	Chiron	Compounds for agrochemicals
	CombiChem	Compounds for agrochemicals
	Diversa	Plant genetics for transgenic crops
Rhone-Poulenc	Agritope	Genomics joint venture for plant traits
	Celera AgGen[f]	Corn genomics
	Mycogen/Dow AgroScience	Genetic traits in crops, marketing
	RhoBio[g]	Genetics for disease resistance
Zeneca	Alanex	Compound libraries for agrochemicals
	Incyte Pharmaceuticals	Plant genomics
	Rossetta Inpharmatics	Compounds for plant genomics

[a] Joint venture between Hoechst (60%) and Schering (40%).
[b] Subsidy of American Home Products.
[c] Joint venture with Institute of Plant Genetics & Crop Plant Research.
[d] Joint venture with Max Planck Institute for Molecular Plant Physiology, Postdam, Germany.
[e] Subsidy of Monsanto through collaboration with Millenium Pharmaceuticals.
[f] Through RhoBio joint venture.
[g] Joint venture with Biogemma.
Source: Thayer, 1999.

lease of any new genetically engineered organism or food (Paoletti and Pimental, 1996). GM products should be evaluated over a long period of time to establish their effects on health, agricultural pests, and the environment. Caution and suitable regulation are necessary to avoid possible environmental and safety problems, which can jeopardize expected benefits of this new science.

The large agrobiotech companies should establish measures to prevent movement of transgenes from pollens to relatives of GM crops or to weeds in nearby farms. In this regard, field test facilities should be carefully designed and suitably located far away from nearby wild relatives or non-GM farms. Genes from some viral pathogens should be carefully and closely monitored to avoid the possibility of their combining with genes of other viral pathogens in the environment. This will prevent creation of entirely new viral strains with dangerous consequences. In addition, insects should be monitored to avoid their becoming resistant to natural toxins in GM plants such as those containing Bt gene. The effect of Bt crops on non-target insects (such as the Monarch butterfly, lacewings, and other insect-eating predators) should be closely monitored before a problem develops.

Antibiotic resistance marker genes used in GM crops should be evaluated to see if they can be substituted with other equally effective selection methods (when available) to protect human health and prevent potential risk of antibiotic resistance in humans and animals (Hileman, 1999b). Some people also suggest that splicing of genes in transgenic crops should be done between organisms closely related on the evolutionary ladder instead of between those widely separated on this ladder to avoid unintended adverse consequences.

Livelihood of farmers in developing countries should be protected by halting development of so-called ‘terminator crops’ which are specially designed to be sterile when their seeds are planted, forcing farmers to buy new seeds every year. Continued production of terminator crops may swing opinion against companies involved in the sterile seed business. Instead, fertile transgenic crops should be sold to these farmers at affordable prices. This will prevent these poor farmers from being dependent on multinationals for their future livelihood. Alternatively GM seeds could be donated freely to poor farmers provided this does not hurt the donor company financially.

Regulatory agencies should set up public health surveillance networks that will quickly flag any problems (such as allergens, toxins), that may arise among people eating GM foods. Researchers and regulators should assess ecological risks before farmers sow any GM crops around the world. Government should restore public confidence in their ability to regulate GM foods by setting up special commissions to advise politicians on long-term impact of GM technologies to human health, agriculture and the environment (Gavaghan, 1999).

Companies involved in GM food production should practice self-policing by conducting rigorous safety and allergenicity testing, promptly withdrawing suspected foods before they hit the market shelf. They should also report any unexpected or potentially adverse effects immediately upon discovery to USDA and FDA. These companies should set up monitoring groups to study the worst case scenarios in concerns for GM foods, and hopefully find ways of mitigating the problem before it happens.

The public needs to be sufficiently educated on genetic engineering of any product to enhance acceptability of such a food. This is because genetic engineering is a relatively new science unfamiliar to many people. Private and public sector leaders should understand the level of consumer’s awareness and acceptability of new biotech products. This will enable them plan a strategy for effective promotion of new GM foods. Industry leaders in GM food technology should take active steps to re-establish trust in the consuming public, especially in Europe, by maintaining a relationship based on openness, honesty, and full disclosure, and by presenting scientific data available to support their claims on the safety of GM foods. They should also promote honest and open debate around the world to discuss the benefits and potential risks of GM foods, and possibly show efforts taken to circumvent those potential risks (Hileman, 1999c). This will go a long way in re-assuring the consumer. They should also carry out a campaign to balance flow of public information about biotechnology by setting up informative websites devoted to promoting benefits of biotechnology, and holding in-depth sessions with members of Congress, universities and colleges, trade associations, grocery manufacturers, food associations, and the news media. Although the companies that develop GM foods and transgenic crops are working hard to set product value and also get a return for their investment in the new technology (costing millions of dollars in R&D efforts), they should also try to satisfy the consuming public, farmers, food marketers, food processors, and everyone else in the food chain.

GM food industry leaders should listen to the consuming public and view public fears as legitimate instead of acting as though such fears arise from ignorance. The companies should consider some form of labeling of GM foods by carefully choosing words that will not hurt their products while placating consumers. For example, some words or phrases such as ‘produced with modern biotechnology,’ and ‘nutritionally enhanced through biotechnology’ may be acceptable to both consumers and manufacturers. They should also encourage farmers to start segregating GM crops from non-GM ones right from the farm, if such crops are intended for export.

Traditional plant breeding as well as organic farming should also continue to complement genetic engineering of plants as an important tool for crop improvement.

7. Conclusions

Adequate regulation, constant monitoring and research are essential to avoid possible harmful effects from GM food technology. The nutritional and health benefits of genetic engineering are so many and will be useful to the growing world population which is currently estimated at six billion (Henkel, 1995; Rudnitsky, 1996), and will probably double by the year 2050, according to the UN. Consequently, genetic engineering is the only logical way of feeding and medicating an overpopulated world (Lesney, 1999). GM has the potential to enhance the quality, nutritional value and variety of food available for human consumption, and to increase the efficiency of food production, food distribution, and waste management. Genetic engineering would also provide raw materials for industrial uses. It would lead to development of new crop varieties that offer increased yields and reduced inputs, and also offer specialized traits that meet end user needs. Genes inserted into plants can give biological defense against diseases and pests, thus reducing the need for expensive chemical pesticides, and convey genetic traits that enable crops to better withstand drought, pH, frost and salt conditions. Use of herbicide resistant seeds will enable farmers to selectively eradicate weeds with herbicides, without damaging farm crops. Genes for different traits (such as herbicide tolerance, insect resistance, slow ripening, etc) can also be stacked in a single seed, thereby enhancing the seed’s efficiency (Thayer, 1999).

There is little or no significant difference between foods genetically engineered and those bred traditionally. It is easier to control products of genetic engineering than those resulting from traditional breeding. GM foods are safe. Careful application of genetic engineering will make life better, improve human health and welfare, and save time and money. It will also reduce processing costs, eliminate harmful wastes, and help the environment. GM will also create jobs and yield sizeable foreign exchange. Overall, the benefits of genetically engineered foods far outweigh the consequences. Risks of producing and consuming new GM foods should be weighed against potential benefits, and when benefits outweigh the risks, such foods should be adopted. Indeed as pointed out by the former FDA commissioner, David Kessler (1993), the people of the 21st century should begin to get used to the emerging technologies of our times, be it microcomputers, information super highways, or genetic engineering.

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