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The Impact of Biotechnology in Agriculture

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ABSTRACT

Crop plants provide essential food nutrients to humans and livestock directly or indirectly. The amount and composition of food nutrients differ greatly in different food crops making plants deficient in some nutrient components. Therefore, depending on one crop plant as a source of nutrients will in addition to not achieving a balanced diet, result in malnutrition and deficiency diseases. Agricultural biotechnology is the application of engineering principles on biological sciences to form new products from raw materials of biological origin. Agricultural biotechnology has been practiced for a long time, as people have sought to improve agriculturally important organisms by natural selection and breeding. A decline in the availability of arable land and supply of irrigation water along with a constant increase in food demands have mounted pressure on farmers to produce more with less resources. A viable solution to this problem is to scale up plant breeding process by the application of biotechnology in agricultural processes. Improved crop disease protection through biotechnology provides a more reliable harvest, which keeps food consistently available and affordable for all consumers. While initial emphasis of agricultural biotechnology has been placed on input traits of crops such as herbicide tolerance, insect resistance and virus resistance, increasing effort and promising proof-of-concept products have been made in output traits including enhancing the nutritional quality of crops. This review aims to look at the positive side of biotechnology in agriculture and highlight few of them.

Keywords: Agricultural Biotechnology, Nutrients, GMOs, Genetic Engineering, Proteomics, Vaccines.

INTRODUCTION

Agricultural technologies in their broadest sense have been responsible for supporting humankind, its population growth, and the expansion of societies' complexity for millennia. Indeed, the ability to meet the world's basic food needs while employing a smaller and smaller proportion of the human population is attributable to the development of increasingly sophisticated agricultural technologies and has allowed the development of complex societies endowed with institutions focused on nonagricultural activities that enrich the overall quality of life. Agronomic practices involving mechanization, soil fertilization, and chemical control of pests and disease along with genetic improvement of crops have been dominant trends.

Some of the greatest advances in crop productivity have involved the deliberate integration of new agronomic practices with genetic improvements. The best-known example is the Green Revolution, which integrated the increased reliance on fertilizer management with new dwarf varieties of wheat and rice. A less well-known example is the integration of mechanical harvesting with tomato varieties bred for both concentrated flowering and firm fruit (1). Both emphasize the integration of genetic and agronomic technologies to optimize crop yields and production efficiency.

Biotechnology has had a great impact on agriculture. It can be defined as the application of engineering principles on biological sciences to form new products from raw materials of biological origin, for example, vaccines or food, Or the use of living organisms and their products to modify or improve human life and environment health [1]. Cheese was probably the first direct products of biotechnology, because it was prepared by adding rennet to sour milk, which is possible only by exposing milk to microbes. Yeast is thought as the oldest microorganisms that have been exploited by humans for their benefit. Yeast has been widely used to make bread, vinegar production, and other fermentation products [2].

In the mid-eighties and early-nineties it became possible to transform plants and animals. However, recognizable modern manifestation in biotechnology began in early1960s [3]. Today, biotechnology has wide-ranging applications, from agriculture to cloning of living organisms and altering life forms. Genetics and biotechnology offer a door to a new era in the history of mankind.

Insulin, used to treat diabetics, and as a blood clot-reducing enzyme for heart attack victims is now produced easily and cheaply as a result of biotechnology. Biotechnology has great potential to improve the quality of human life by improving their health by providing them more nutritious food with improved environmental conditions. It can ensure sustainable development by improving agricultural productivity.

Plants are the primary source of food for humans and feed for livestock. Through domestication and agricultural activities of breeding and selection, plants were developed into food crops that serve as the major source of dietary carbohydrates, lipids, proteins, vitamins and minerals for humans and livestock. The level and composition of food nutrients vary significantly in different food crops. As a result, individual plant foods are often deficient in certain nutrient components. For example, while root and tuber crops are rich in carbohydrates, they are low in protein. Legumes are usually high in protein, but deficient in essential amino acids methionine, and milled rice is rich in starch but contain little essential amino acid lysine, iron, and no pro vitamin A (ß-carotene).

Relying on a single food crop such as cassava or rice as major staple source of nutrients thus will not attain a nutritionally complete diet and result in malnutrition and deficiency diseases, which often occur in populations of developing countries, due mainly to poverty. Effort to improve the nutritional quality of crops by conventional breeding and selection method, in general, has not met with desired success. Even in promising cases, the improvements often associate with undesirable agronomic traits.

Recent advancements in plant sciences and agricultural biotechnology offer new opportunities and possibilities to improve the yield, quality, and production economics of food crops. Although the first generation biotech crops have been dominated by input traits since their commercialization in 1996, such as herbicide tolerance, insect and virus resistance soybeans, corn and canola, interest and effort in research and development of crops with output traits including enhancement of food nutrition with output traits been generated, demonstrating that it is feasible to improve food nutrition. Agricultural biotechnology has been practiced for a long time, as people have sought to improve agriculturally important organisms by selection and breeding. An example of traditional agricultural biotechnology is the development of disease-resistant wheat varieties by cross-breeding different wheat types until the desired disease resistance was present in a resulting new variety.

Application of Biotechnology in Agriculture

There are several important applications of molecular biology and biotechnology in agriculture including plant genetic engineering, the use of proteomics for crop improvement, introduction of insect-resistant and herbicide-tolerant seed, use of genetically modified (GM) crops as feed, plant-based vaccine manufacturing, analysis of food quality, safety and nutritional values among many others.

Plant Genetic Engineering

Genetically engineered (GE) crops are widely referred to as GMOs (genetically modified organisms). Plant genetic engineering (GE) is a technology developed in the early 1980s that reached its first commercial launch in the mid-1990s and relies on the ability to transfer novel genes to crop plants by nonsexual means. This new technology expanded the gene pool available for crop improvement from a narrow base of closely related plant species to a theoretically infinite gene pool, encompassing the genes present in all organisms as well as entirely synthetic genes. In addition to expanding the gene pool, GE, in comparison to traditional plant breeding, allows the relatively rapid and precise transfer of new traits into crop plants.

Although the first genetically modified (GM) crop was the Flavr Savr™ tomato, engineered to extend fruit shelf life and quality, the first generation of GM crops incorporates so called production traits, which confer insect resistance, disease (virus) resistance, or herbicide tolerance. The GM crop pipeline now includes second-generation traits, which include enhanced product quality and composition, tolerance to abiotic stress, nutrient-use and photosynthetic efficiency, and nutritional enhancement, among others. Notably, a few GM crops have been introduced and withdrawn from the market, potentially reflecting their lack of commercial viability, and a few GM crops have come to dominate the GM crop market and continue to increase their influence, reflecting their strong adoption by farmers globally.

A 2013 survey by the International Service for the Acquisition of Agri-biotech Applications shows that the total global land area of GM crops reached 170 million ha in 2012, a 100-fold increase in the adoption of biotechnology crops since 1996. Currently, about 59 countries have granted regulatory approval for import or use of ~30 GM crops. Of these, 28 countries, including 20 developed and 8 developing, planted commercialized GM crops in 2012 (3, 4). For the first time, planted GM cropland area in developing countries (52%) has surpassed that of developed countries (48%).

The Use of Proteomics for Crop Improvement

The knowledge of key proteins that play crucial roles in the proper growth and development of a plant are critical to propel the biotechnological improvement of crop plants. These proteins maintain cellular homeostasis under a given environment by controlling physiological and biochemical pathways. A search of the published research literature revealed that genomics and proteomics are the two major wheels that keep the discovery of novel genes rolling, which can eventually be placed into the pipeline for crop improvement programs.

Two-dimensional electrophoresis (2-DE) and mass spectroscopy (MS), two of the most widely used proteomics methods, are used to catalog and identify proteins in different proteome states or environments. Advancesin 2-DE has been extremely helpful in bringing proteomics close to biotechnological programs. However, due to some drawbacks and disadvantages associated with gel-based proteomics, e.g., labor intensiveness, insensitiveness to low-copy number proteins, low reproducibility and the inability to characterize complete proteomes, many gel-free proteomic techniques have also become a valuable tool for scientists [4]; [5]; [6]; [7].

Proteomics offers novel gene (DNA) identifications to plant biologists and breeders. Marker-assisted selection (MAS), which is the employment of DNA markers in a plant breeding program, has extensively been used to select desired genes/quantitative trait loci (QTLs) in the development of a comparatively superior breeding line [8]. [9] used an approach that brought proteomic and MAS components together; they identified protein quantity loci (PQL) that explained some of the spot intensity variation. Of the 72 proteins analyzed, 70 PQLs were identified for 42 proteins, 20 of which had more than one PQL.

This type of approach is especially useful in breeding programs because, through intensive breeding selection, lines could be available with differing phenotypic degrees that help in drawing correlations between responsive genes and observed stress tolerance phenotypes. This correlation can further be verified by analyzing advanced mapping populations such as recombinant inbred lines (RILs), near isogenic lines (NILs), and double haploid lines [10]. Furthermore, the co-segregation of a protein and the QTL (or the trait) can be studied in the two parental lines from which the mapping populations were developed.

Finally, the plant breeders should be able to integrate the selected genes in marker-assisted breeding programs to improve the trait under study [11]. The major limitation of this technique is that it works only within the same species because the parents need to be cross-compatible to transfer the superior genes/alleles through this molecular breeding approach. Under such limitations, embryo rescue or genetic engineering, which has no boundaries for gene transfer, could be very useful [12].

Introduction of Insect-Resistant and Herbicide-Tolerant Seed

The first generation of agricultural biotechnology introduced insect-resistant and herbicide-tolerant traits into four principle row crops. The insect-resistant trait, introduced into corn, cotton, and soybeans, caused crop plants to produce naturally occurring chemicals *Bacillus thuringiensis* (Bt), which is toxic to common agricultural pests, such as the European corn borer, but harmless to humans and relatively environmentally benign. In producing the toxin, which has been applied to plants for nearly a century and is employed in modern organic farming, insect-resistant crop plants rebuff pests without farmers' application of chemicals. The herbicide-tolerant crops express tolerance to glyphosates, a class of broad-spectrum, low-toxicity herbicides that include Roundup, a Monsanto product employed also in residential settings.

Such tolerance, introduced into corn, soybeans, and canola, allows farmers to control weeds more easily. In the absence of herbicide-tolerant varieties, farmers must rely more heavily on either controlling weeds before crop emergence. For example, by repeatedly tilling the soil in a process that causes erosion or applying relatively more toxic "narrow spectrum" chemicals that can target weeds without affecting post-emergent crops.

Genetically engineered crops were quickly adopted following commercialization in 1996. By 2010, genetically engineered crops were annually planted across 140 million hectares in 29 countries. The technology was adopted on 42 percent of land planted to the four principal genetically engineered crops: corn, soybean, cotton, and rapeseed. Twenty percent of all cropland was planted to genetically engineered seed.

Genetically engineered seed was planted to 70 percent of total soybean area, 25 percent of total corn area, 60 percent of total cotton area, and 20 percent of total rapeseed area. The majority of genetically engineered crop area was concentrated among a few countries that aggressively adopted the technologies: the United States and Brazil planted 85 percent of genetically engineered corn, and Argentina, 92 percent of genetically engineered soybean. Ninety percent of genetically engineered cotton was planted in India, China, and the United States, while Canada alone planted 85 percent of genetically engineered rapeseed.

GM Crops Are Used as Feed in Many Countries

About 70% to 90% of the globally produced GM crops are used as feed for food-producing animals. In the USA itself, with a high adoption of GM crops, more than 95% of food-producing animals consume GM feed. During the last decade alone, this corresponded to more than 100 billion animals. Health and performance of these animals is closely monitored. No detrimental effects of the GM feed versus conventional feed were

observed when analyzing this very large dataset [13].
The global demand for certified non-GM feed is quite limited. For soybean, the share of this niche market has been estimated to be less than 4.5%, for maize at around 7% of traded commodities. Given the wide adoption of GM varieties in main export countries, more than 90% of the globally traded soybean may contain GM. For the European Union (EU), less than 15% of the about 30 million tons of soybeans and soy products for feed imported each year (more than 60 kg per EU citizen) are identity-preserved certified GM free. The large majority of soy-based animal feed in the EU, thus, contains genetically modified components [14].

Plant-based vaccine manufacturing

An antigen of interest, when over expressed in plant tissues by a biotechnological approach, is considered to be a plant-based vaccine [15]. In situations dealing with a poorly characterized pathogen, a genomic or proteomic approach is specifically useful to identify the candidate antigens that possess favorable characteristics [16]; [17]. A major advantage of plant-based vaccines is "no safety concerns" [18]; [19]. The production of vaccine antigens in plants can be achieved through, either stable expression or transient expression systems. The stable genetic transformation produces a genetically engineered plant producing the antigen, and this plant can be propagated either asexually through stem cuttings or sexually through seeds [20].
On the other hand, transient expression uses recombinant plant virus that carries the vaccine gene and directs the plant to produce the antigen via systematic infection [21]. Tomato is good alternative for edible vaccines and was used to express orally immunogenic respiratory syncytial virus (RSV) fusion (F) protein in the fruit [22]. Banana is also another good alternative for edible plant vaccines since it is widely grown and transformation has been reported [23]. Potato is considered a good model for edible vaccines and the first edible vaccine was tested in potatoes [7]. However, from an economic point of view, it would be better if major crops such as soy bean, alfalfa, or corn can also be made efficient plant systems for recombinant antigen protein production [9].
Enterotoxigenic bacteria such as *Escherichia* and Cholera cause diarrhea due to the secretion of toxins that specifically bind to G_{M1} gangliosides present on epithelial cell surfaces of small intestine [11]. Cholera toxin (CT) and *E. coli* liable toxin (LT) are homologous multi-subunit proteins in which the non-toxic B subunit mediates G_{M1} and thus can be candidates for vaccines that can neutralize toxin activity. Both LT-B [8] [9] expressed in transgenic potatoes produced toxin-protective intestinal antibody responses after ingestion, and this shows that plants produced correctly folded proteins and assembled native G_{M1}-binding parametric complexes. LT-B potatoes have been used in a clinical study to test the edible plant vaccine [13]. Transgenic plant material expressing the antigen, are capable of simulating the antibody response in humans. Several clinical trials have also been performed for other projects, e.g., rabies [4], and *E. coli* O157:H7 [8]. A step ahead, [11] described a fully automated "factory" that uses tobacco plants to produce large quantities of vaccines and other therapeutic biologics within weeks using a biotechnology approach, representing a perfect example and motivation for future endeavors in this direction.

Analysis of Food Quality, Safety and Nutritional Values

The field of proteomics has been used to analyze the differences between the nutritional values of food crops through the analysis of their proteomes. [3] reported that heat stress increased the expression of invertases in tomato fruits, thus increasing their sucrose content and producing sweeter tomatoes. As physiological disorders appear in crop if they are not harvested at right stage and may result in huge economic losses [7]; [8], [9], proteomic-based approaches have become useful to detect biomarkers for optimal harvest maturity [10].

Analysis of post-harvest withering process in grapes is very critical to produce high quality wines, and thus gel-based proteomics analysis of this process has been employed for improving grape quality [21]. Also understanding the ripening and post-harvest physiology during storage will not only have impact on food quality but also on the optimization of the technological processes involved. Proteomics have investigated the reason that heat treatment for peach fruits will improve the peach fruit quality and shelf-life, and the reason was the differentially expressed proteins that were involved in fruit development and ripening [8].

On the other hand, in cereal industry, proteomics was used for investigating the protein biomarkers for the selection of suitable durum wheat cultivars for pasta making [13]. Flour quality is highly correlated with protein composition and functional quality, thus proteomics can be very useful to identify protein markers for suitable cultivars for flour making [8]. The proteomic analysis of wheat kernels for amphiphilic proteins increased the knowledge of the physiological and technological functions of wheat kernels [3]. [4] used 2-DE approach to identify the soluble proteins that play an important role in stabilizing the gas bubbles in dough and influencing the crumbling structure of proteins.

Proteomics has also helped in the construction of proteome map investigating the level of protein modification during barley malting and detecting the proteins associated with beer quality [20]. Proteomics also had a role in food authenticity, through using sensitive protein biomarkers [17]. Proteomics was used to identify cheaper sub- stitutes for cheaper cultivars of coffee varieties through the use of specific biomarkers [7]. Plant or fruit extracts used in formulas can also be authenticated by the use of protein biomarkers to assess the genuineness of the formula or product [12] [13].

Food allergens are a great threat to people suffering from such allergies. Proteomics is a crucial field for sensitively detecting and quantifying food allergens. A combination of 2-DE and IgE reactive proteins using an allergic patient's sera has been applied as an approach to characterize the allergenicity of food proteins [11]; [12]. [13] compared the allergenic potency of maize pollen and the native grass *Phleumpratense* using 2-DE followed by immuno-blotting, and found that maize pollen showed less allergic response in comparison to the native grass due to lower allergen content and lower allergic groups found in maize pollen.

[23] also studied apple allergen using 2-DE with IgE immune-blotting and identified four new apple allergens known as Mald1, Mald2, Mald3, and Mald4. Proteomic analysis of rice leaf, root, and seed showed the presence of many allergenic proteins in the seeds, which implicate the uses of proteomic analysis of foods for the presence of allergens [8]. Shotgun proteomics was also used to characterize the allergenicity of certain foods [4]; [5]. The generated information is a key for targeted approaches, such as selective reaction monitoring (SRM), which not only detect the allergen but also quantify it [17].

Over the years, proteomics has been used to investigate "plant-based bioactives" to improve the nutritional value of food crops. Bioactives are the peptides that are released either during digestion by the host enzymes or during food processing and ripening by microbial enzymes [14]. Bioactives were reported from different plant sources, such as wheat, rice, maize, soybean, mushrooms, pumpkins, and sorghum [15]. Soybean bioactive peptides, such as lunasin, Bowman–Birk inhibitor, lectin, and beta-conglycinin, have attracted the attention of researchers who study their antioxidant activities (de Lumen, 2005) to treat oxidative stress in the future [16]. Lupin also contains alpha and beta-conglutins as storage proteins and appears to have bioactive effects [17].

CONCLUSION

Modern biotechnology represents unique applications of science that can be used for the betterment of society through development of crops with improved nutritional quality, resistance to pests and diseases, and reduced cost of production. Biotechnology, in the form of genetic engineering, is a facet of science that has the potential to provide important benefits if used carefully and ethically. Society should be provided with a balanced view of the fundamentals of biotechnology and genetic engineering, the processes used in developing transgenic organisms, the types of genetic material used, and the benefits and risks of the new technology.

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