The Omics Revolution in Agricultural Research
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ABSTRACT: The Agrochemicals Division cosponsored the 13th International Union of Pure and Applied Chemistry International Congress of Pesticide Chemistry held as part of the 248th National Meeting and Exposition of the American Chemical Society in San Francisco, CA, USA, August 10−14, 2014. The topic of the Congress was Crop, Environment, and Public Health Protection; Technologies for a Changing World. Over 1000 delegates participated in the Congress with interactive scientific programming in nine major topic areas including the challenges and opportunities of agricultural biotechnology. Plenary speakers addressed global issues related to the Congress theme prior to the daily technical sessions. The plenary lecture addressing the challenges and opportunities that omic technologies provide agricultural research is presented here. The plenary lecture provided the diverse audience with information on a complex subject to stimulate research ideas and provide a glimpse of the impact of omics on agricultural research.

KEYWORDS: agricultural research, biotech crops, genetic modifications, genomics, metabolomics, omics, plant breeding, plant transcriptomics, proteomics, transgenic crops

INTRODUCTION

Omic can inform you if the steak you are about to enjoy will be tender and juicy or if your glass of wine will be sweet or dry before your first sip and can provide you a genetic map to growing the deepest-red tomato possible. The panomic arsenal of omic tools is enhancing the quality, taste, and nutritional composition of plant crops; increasing agricultural production for food, feed, and energy; playing a significant role in crop protection; and significantly affecting agricultural economics. Through the use of genomics, proteomics, transcriptomics, and metabolomics, the consistency and predictability in plant breeding have been improved, reducing the time and expense of producing better quality food crops that are resistant to stress but still exhibit a high nutritional value. Omics has provided insights to the molecular mechanisms of insect resistance to pesticides, and the tolerance of plants to herbicides for better pest management. Linking genes to traits provides more scientific certainty leading to improved cultivars and understanding the mechanisms of insect and weed resistance. Omics enables a systems biology approach toward understanding the complex interactions between genes, proteins, and metabolites within the resulting phenotype. This integrated approach relies heavily on chemical analytical methods, bioinformatics, and computational analysis and many disciplines of biology, leading to crop protection and improvements.

The National Agricultural Biotechnology Council in its report "Vision for Agricultural Research and Development in the 21st Century" outlined its plan for developing a sustainable biobased economy.1 The Council urged agricultural research and development programs to look beyond food, feed, and fiber production and to address sustainable biobased industries. This in part would create rural and urban job opportunities; improve the quality of air, water, and soil; improve the healthfulness of food; and produce human health-related products in plants, microbes, and animals.1 Good ideas, but how do we get there?

EARLY CROP IMPROVEMENT TECHNIQUES

The genetic makeup of plants has been intentionally altered since the initial start of agriculture, estimated to have its beginnings 8000−10000 years ago. The evolution of crop domestication, which was essentially genetic manipulation, was based on selective breeding to produce better plants and animals and resulted in genetic modifications, although not recognized at the time. In these early experiments, only the seeds from the best-looking plants were saved for the next planting cycle. Traits such as higher yields, pest and disease resistance, larger fruits or vegetables, and faster growth were commonly selected. Farm animals were also selectively bred for higher yields of milk and meat.

Luther Burbank developed the "plumcot" by crossing plums with apricots, 100 years ago and described the process in his 1921 book How Plants are Trained to Work for Man: Fruit Improvement.2 Plumcots are still on the market today along with many other hybrids including more from plums and apricots. Broccoflower, another well-known genetic modification, is said to have more vitamins than either the broccoli or cauliflower parent. Products of plant genetic manipulations based on chemical treatment and radiation are also well-known commodities. When the seeds from seeded watermelons are treated with colchicine, a triploid seed is produced that is sterile, leading to no seeds in the fruit. This may be convenient for eating, but it takes away one of the pleasures of eating watermelon—the seed-spitting contests.

During mutation breeding, plants are exposed to γ-rays, protons, neutrons, and α- and β-particles to induce mutations.

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to obtain the desired traits. Chemicals such as sodium azide and ethyl methanesulfonate are also used to produce mutagenic plants. Over 3200 mutagenic plant varietals have been officially released between 1930 and 2014. Of this number, over 1000 mutant varietals are of major staple crops being grown worldwide. After World War II, giant “gamma gardens” sprang up on government installations in several countries to support peaceful uses of atomic energy. A popular variety of red grapefruit was created via thermal neutron radiation at Brookhaven National Laboratory. Plants developed via mutagenic processes or cross breeding possess random, multiple, and unspecific genetic changes often leading to thousands of undesirable plants to finally obtain the ones with the desired traits. These nonspecific genetic manipulations have a high potential to result in unintended and perhaps adverse compositional changes. However, the successful products of these genetic manipulations have led to searches for more efficient and controllable ways to transfer genetic traits among plants while lowering risks of adverse mutations using precision genetic modifications.

**Omic Technologies.** The suffix “omics” has been attached to many fields of study, instantly conferring buzzword status and attention (Figure 1). The world of omics is quickly becoming a vast field and impossible to cover properly in just one paper. Several global omics technologies (Figure 2) are presented here in relation to agricultural research applications.

Omic technologies allow the visualization or monitoring of all of the changes that take place when the genetics, nutritional state, or environment of an organism is altered, thus revealing an understanding of the alterations in plant metabolism resulting from environmental interactions. Omics can provide insights into species that we thought we knew everything about. The central Asian wild apple was long thought to be the main progenitor of the domesticated apple. However, using genomic markers it has been found that the European crabapple made an unexpectedly large contribution to the genome of the domestic apple *Malus domestica.* The genetic probing into the lives of plants can be quite fruitful. Studies on cultivated tomatoes revealed genetic changes over time through early domestication and modern plant breeding that has led to today’s cultivars being much larger than their wild relatives.

Using omics, the genes responsible for proteins that confer or block the desired traits can be determined. Once these genes have been identified, they can be silenced in a plant or introduced from one plant to another or from another species, making a transgenic plant (Figure 3). Thus, a transgenic plant contains a gene or genes (i.e., transgenes) that have been artificially inserted rather than the plant acquiring them through pollination. Transgenic crop varieties possess a variety of useful agronomic traits. By inserting one or two target genes that encode for specific desirable traits into crop plants in vitro, new plant varieties with specified traits are developed in a more precise manner than conventional plant breeding.

In the 1980s researchers developed more precise and controllable methods of genetic engineering to create plants with desirable traits. In 1990, the U.S. Food and Drug Administration (FDA) approved the first genetically engineered food ingredient for human consumption, the enzyme chymosin, which is used in 70% or more of the cheesemaking in the United States. In 1994, the FlavrSavr tomato was the first...
genetically engineered food approved for human consumption in the United States. The FlavrSavr was developed to have more flavor and to have a longer shelf life. Rice fortified with β-carotene, known as Golden Rice, appeared in 1999 to prevent blindness due to a lack of vitamin A. Some of the other first biotechnology products to be commercialized were modifications that make insect, virus, and weed control easier or more efficient. These modified traits now account for the majority of soybeans, cotton, and corn grown in the United States.

Genomics. Genomics is a good entry point for the omics field, particularly as the omics nomenclature started with the coining of the word “genomics”. A plant’s domestication and breeding history are recorded in its genome. The completion of the sequence of the first plant genome, Arabidopsis thaliana (i.e., thale cress), ushered in the post genomic era in plant research. The Human Genome Project revealed that there are about 20500 human genes, whereas A. thaliana is reported to have 25498 genes. These genomes were completed along with the rice genome in the early 2000s. Databases of genetic sequences have been compiled based on submissions from researchers to foster collaborations. GenBank is an annotated collection of publicly available DNA sequences that is frequently updated to provide the latest DNA sequence information.

Genomics provides knowledge-based approaches for crop plant biotechnology, enabling precise, and controllable methods for molecular breeding and marker-assisted selection, accelerating the development of new crop varieties. However, time is not the only advantage as new attributes not imagined before the omics era can be introduced into plants, such as the production of biopharmaceuticals and industrial compounds. Gene expression studies identify functional gene products that give rise to the phenotype, which is information that can be used for plant improvements. By adding a specific gene or genes to a plant, or knocking down a gene with RNAi, the desirable phenotype can be produced more quickly than through traditional plant breeding.

Figure 3. Simplified description for making a transgenic plant that is both drought tolerant and high in nutrient content. In agriculture, the bacteria Agrobacterium tumefaciens is often used as a vector to deliver genes into plants. The bacteria are parasites with the natural ability to transfer their genes into plants.
Transcriptomics. The complete set of RNA, also known as the transcriptome, is edited and becomes mRNA, which carries information to the ribosome, the protein factory of the cell, translating the message into protein. Transcriptomics has been described as expression profiling, as it is a study of the expression levels of mRNAs in a given cell population. Unlike the genome, which is roughly fixed for a given cell line, with the exception of mutations, the transcriptome is dynamic as it is essentially a reflection of the genes that are actively expressed at any given time under various conditions. Transcriptomics determines how the pattern of gene expression changes due to internal and external factors such as biotic and abiotic stress. Transcriptomics is a powerful tool for understanding biological systems. Transcriptomic techniques such as next-generation sequencing (NGS) provide capability for furthering the understanding of the functional elements of the genome.17

Proteomics. Proteins are everywhere in plants and are responsible for many cell functions. Through proteomics it can be determined whether expression of mRNA results in protein synthesis to further illuminate gene function. The hundreds of thousands of distinct proteins in plants play key functional roles for the texture, yield, flavor, and nutritional value of virtually all food products.18 Through protein expression profiling, proteins can be identified at a specific time as a result of expression to a stimulus such as disease and insect infestation or temperature and drought, further elucidating the function of particular proteins. Comparative proteomics can determine the molecular mechanisms for susceptibility or resistance to enhance resistance traits.

Protein patterns have been used to study the foam stabilization of Champagne and sparkling wines and the effect of fungal pathogens on grapes and wine authentication and to determine if grapes were indeed grown in the appropriate appellation.19 Proteomics can also enhance the understanding of mechanisms of resistance, mode of action, and biodegradation of pesticides, aiding in the discovery of new effective and safe pesticides.

Translational plant proteomics is an expansion of proteomics from expression to functional, structural, and finally the translation and manifestation of desired traits. Through translational proteomics the outcomes of proteomics for food authenticity, food security and safety, energy sustainability, human health, increased economic values, and environmental stewardship can be applied.20

Metabolomics. Metabolomics is the study of chemical processes providing a linkage between genotypes and phenotypes.21 Proteomics identifies the gene products produced, whereas metabolomic studies determine whether the expressed proteins are metabolically active and identify biochemical processes and the roles of the resulting various metabolites. The metabolome is dynamic and subject to environmental and internal conditions. The simultaneous monitoring of metabolic networks enables the association of changes resulting from biotic or abiotic stress, which can aid in the development of improved crop varieties and a basic understanding of systems biology.22 Metabolic profiling provides an instantaneous picture of what is occurring in the cell, for example, during fruit ripening, identifying key compounds important for imparting taste and aroma. Monitoring changes in metabolite patterns can lead to quality improvements for nutrition and plant health.22 Changes in the metabolome can also help to distinguish the mode of action of pesticides, providing critical information for new pesticide discoveries.

Metabolomics can provide an indication of the equivalency or compositional similarity between conventional and altered plants and determine if undesirable changes have occurred in the overall metabolite composition. Metabolic profiling through mass spectrometry (MS) and nuclear magnetic resonance (NMR) analyses have been used to ascertain metabolic responses to herbicides and investigate metabolic regulation and metabolite changes related to environmental conditions of light, temperature, humidity, soil type, salinity, fertilizers, pests and pesticides, and genetic perturbations.21,22 The in-depth analysis of metabolites may be helpful for developing new pesticides, decreasing pesticide usage, increasing nutritive values, or assisting with other key traits.

METHODS OF ANALYSIS

The field of omics and particularly proteomics has been driven by major improvements in MS instrumentation, advanced data analysis, bioinformatics, and rapid analytical methods such as DNA microarrays to screen thousands of samples within a short time. High-resolution NMR spectroscopy has also been applied to omic studies. However, complex spectra are often obtained, and it is typically not as sensitive as MS. An in-depth review of NMR theory and its applications to omics has been published.23 Numerous hyphenated techniques have been used to analyze transgenic food for safety and risk assessments.24,25 Advances in large-scale data generation require concomitant advances in bioinformatic tools to process in-depth information essential for the comparative studies of genes and protein expression and regulation.

The two major analytical proteomic approaches are termed top-down and bottom-up. In a top-down approach intact proteins are analyzed by MS. The bottom-up approach (commonly referred to as shotgun proteomics) starts with a proteolytic digestion followed by separation of the resulting peptides with detection by MS/MS. The masses of the resulting peptides are compared with theoretical peptide masses. Search engines are used to match the spectra generated by the MS/MS analysis with peptides from a target protein sequence database.

Matrix-assisted laser desorption/ionization (MALDI) imaging enables the visualization of the spatial distribution of proteins and metabolites. The proteome of the common apple was determined using two-dimensional polyacrylamide gel electrophoresis and matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS/MS). These types of proteomic studies further the understanding of the genetic regulation of fruit ripening and the changes that occur during storage to identify key parameters for maintaining nutrition upon storage and to prevent spoilage.26 MALDI-TOF MS/MS has shown application for the authentication of foods, critical for food safety, quality assurance, and international trade. The geographical origins of several honeys were differentiated on the basis of individual protein fingerprints using MALDI-TOF MS/MS.27 The approach of using MS profiles of proteins can be applied to other food commodities to satisfy quality assurance requirements such as for verifying the country of origin. Although wines are not known for their protein content, proteins are important factors in the quality of individual wines. In addition to the effect of wine proteins on foaming, important for sparkling wines, they also influence astringency, color stability, and other factors leading to the overall quality of the wine.19 Proteomic studies can provide a
quality assurance measure for this often expensive commodity. Two-dimensional electrophoresis (2-DE) with immunochemical and tandem MS detection can highlight differences in protein profiles of wine from healthy and diseased grapes. Interfacing MS with protein databases provides not only protein characterization but also mapping of post-translational and other chemical modifications and determines interactions between proteins and ligands, providing data to address issues of food quality, safety, traceability, and structure/function relationships of food proteins and peptides. Proteinomic software, such as Scaffold, enables in-depth visualization of the data and clusters similar proteins with shared peptides for comparisons.

Advances in analytical methods will further advance the applications of omics. Second-generation proteomics employs stable isotope labeling of amino acids in cell culture (SILAC) and other quantitative methods for high-throughput measurement of protein dynamics and interactions rather than just identification by MS. Third-generation techniques look at and compare entire proteomics over time and space, which requires large-capacity data analysis. Accelerator MS has proven useful for metabolic profiling in humans, and it is anticipated that it will play an increasing role in plant metabolomics.

OMICS OPPORTUNITIES, APPLICATIONS, AND RESEARCH

Herbicide and Insect Resistance. Herbicides typically work by binding to plant enzymes to inhibit their action. Crops modified to make different proteins or target sites that are not inhibited by a particular chemical can provide herbicide resistance to the crop, leaving weeds vulnerable. For example, plants that are resistant to glyphosate have been engineered to express a different protein that is not inhibited by the herbicide. The planting of herbicide-resistant (HT) soybeans, cotton, and corn has dramatically risen in the United States since when they were first introduced.

The soil bacterium Bacillus thuringiensis (Bt) produces a protein that is toxic to specific insect pests (i.e., corn rootworm, corn earworm, European corn borer, and cotton bollworm). The insertion of this gene into corn and cotton plants provides protection from these pests throughout the plant’s lifespan. Two different traits can be combined (i.e., stacked) in the same plant such as HT with Bt for added benefit. The stacked traits of both HT and Bt production accounted for 79% of the cotton grown in the United States in 2014, and 76% of corn was stacked.

Oomics also enables the study of the evolution of herbicide and insecticide resistance and the biochemical and molecular mechanisms underlying resistance. Gene amplification studies provide information on resistance evolution, chemical selectivity, and the link between resistance and host plant adaptation. Such studies can lead to more efficient pesticides closely allied with defense mechanisms of insects and plants and enable more tailored crop protection strategies.

Food Safety. Omic techniques can be applied throughout each food-processing step (from raw materials to end products) to maintain quality, improve shelf life predictions, and signal microbial contamination in real time to improve facility sanitation and increase safety assurance. Food authenticity and adulterations, allergen detection (peptide markers), biomarkers for meat tenderness, and protein profiles can all be determined through omics. 

Edible Vaccines. An alternative to an injection for vaccination would be to enjoy a fruit or vegetable engineered to produce a vaccine. Tomatoes and bananas have been reported to produce vaccines in their fruit to diphtheria, pertussis, polio, measles, tetanus, tuberculosis, and hepatitis B. These edible vaccines could lead to low-cost protection, particularly in poorer countries with low vaccination rates, to provide community immunity and livestock protection. Plantibodies. Antibodies produced in planta can yield gram level amounts in just a few weeks, a significant advantage over other procedures. A comparison of therapeutic monoclonal antibodies produced from plants with antibodies produced conventionally showed that the plantibodies could fight the West Nile virus infection in mice as well as the more conventional and costly version of the same antibody grown in mammalian cells. Antibodies from the leaves of a transgenic tobacco plant were found to neutralize various types of rabies viruses. Clinical trials of anti-HIV plantibodies have already been approved in the United Kingdom. The potential for plant-based antibodies to provide the same therapeutic benefits at a lower cost is extremely attractive and opens vast areas of the world to better health care. Plants as bioreactors for the production of therapeutic proteins have several advantages, including the lack of animal pathogenic contaminants, low cost of production, and ease of agricultural scale-up.

Another genetically modified strain of tobacco produces an antibody for the environmental toxin microcystin. The plants secrete the antibody from their roots and bind the toxin, extracting it from the environment. One can envision the use of such plants for reducing the bioavailability of toxins, remediating contaminated water or soils, and giving new meaning to the term phytoremediation. Plants as Synthetic Chemists. With a little encouragement, plants are excellent synthetic chemists for a wide range of compounds. Biotech crops have enabled an increase in the oleic acid content of vegetable oils, with simultaneous reduction in polyunsaturated fatty acids. This shift in ratios conferred the added advantage of increasing the stability of the vegetable oil and ultimately the processed foods. Although traditional plant breeding allowed a modest increase in oleic acid, biotechnology was necessary to achieve the higher levels (75–80%) desired. Through gene silencing, high oleic acid (78%) and high stearic acid (40%) cottonseed oils have been produced.

In addition to these synthetic capabilities, as well as producing antibodies, vaccines, and other biological compounds (e.g., human serum albumin, cytokines, human growth hormone, pancreatic lipases), plants can also produce industrial compounds. Plants can outperform bacteria in post-translational modifications of proteins and are being considered as vehicles for producing plastics, polymers, and other industrial building blocks.

Human Exposure Assessment. Omics can significantly contribute to our knowledge of biomarkers of exposure. The SILAC procedure coupled with HPLC-MS/MS detection is a proteomic approach useful for determining biomarkers of exposure and for linking exposure to molecular initiating events and finally to adverse outcome pathways (AOPs). In the SILAC approach either C12− or C13−labeled amino acids are added to the growth media of separately cultured, but identical, cell lines, giving rise to cells containing either light or heavy protein chains. A comparative analysis provides a measurement of protein dynamics and interactions rather than just
identification of proteins. Linking omics and genetic data to pharmacokinetic and pharmacodynamic exposure models can provide in-depth ecological and human health risk assessments.

Energy Sustainability. Changing climate, rising fuel prices, and an increased desire to use renewable energy sources will drive this research further. For example, cultivation of a nondomesticated oilseed shrub which grows in adverse conditions can produce oil that is easily converted to biodiesel. Maize, sugar cane, and rapeseed can be major sources of green energy, particularly through modification. The development of cost-competitive advanced biofuels from nonfood biomass resources may reduce greenhouse gas emissions by ≥50% versus petroleum-based alternatives. Transcriptome profiling, whole genome sequencing, and molecular markers are approaches being investigated for developing *Jatropha curcas* Linn. (another nondomesticated shrub) as a sustainable biofuel crop. Another potential is African grain sorghum that requires minimal fertilizer and water compared to cereal crops and has readily fermentable sugars. Proteomic data from molecular breeding studies can assist with the further utilization of plants as sources for the sustainable production of biofuels without reducing food production.

Bioeconomy. The National Research Council report on research and commercialization of biobased industrial products provides a foundation for the National Bioeconomy Blueprint. The blueprint highlights several key areas for supporting research and development investments to foster a bioeconomy, including facilitating the transition of new translational products from research laboratory to market while protecting human and environmental health.

The growth of today’s U.S. bioeconomy is due in large part to the development of omic technologies. According to the U.S. Department of Agriculture, U.S. revenues in 2010 from genetically modified food crops were approximately $76 billion and revenues from fuels, materials, chemicals, and industrial enzymes derived from genetically modified systems were approximately $100 billion.

CONTINUING TRENDS

Global studies support the contribution biotech crops have made to food security and sustainability while positively affecting the environment by increasing crop production with a reduction in pesticide usage, decreasing CO₂ emissions, conserving biodiversity, and helping small and resource poor farmers become self-sufficient. Confining cultivation to cropland saves forest and protects biodiversity. The United States continued to be the largest commercial grower of biotech crops with 73.1 million hectares (40% of global share) devoted to maize, soybean, and cotton, followed by Brazil and Argentina (24.3 million hectares), India (11.6 million hectares of Bt cotton), and Canada with 11.5 million hectares.

In 2014, 18 million farmers, of which 90% were poor with small farms, planted a record 81 million hectares of biotech crops in 28 countries. Over 15 million hectares of Bt cotton in 2014 were planted by small-scale farmers in China and India, and 415,000 small-scale farmers in the Philippines benefited from biotech maize. Bangladesh planted Bt eggplant for the first time in 2014 and is field-testing biotech potatoes and exploring biotech cotton and rice. Indonesia planted drought-tolerant sugar cane and Brazil a HT soybean, and Vietnam approved biotech maize. All of these plantings are contributing to a more stable food supply worldwide. The United States recently approved a reduced-lignin alfalfa with higher digestibility and yield and a potato that when fried produces 50–70% less acrylamide. The potato does not contain genes from other species but fragments of a related wild potato DNA that silence the potato’s own genes for production of certain enzymes.

NEED FOR CONTINUED CROP IMPROVEMENTS

Projections on world population growth coupled with a shrinking amount of prime agricultural land, which is forcing the use of suboptimal land for crops, indicates the continued need for improvements in agriculture. Climate change and the impact of agriculture on climate change are also factors. Climate change is normal, but the rate of change in recent years exceeds normal. Climate change affects several aspects of agriculture including soil warming and increasing soil respiration. The development of plants with attributes of drought and salt tolerance and early maturation will help to address the trend of declining rainfall and increasing temperatures in agricultural areas and overcome the increased susceptibilities to disease and pests. Plants that are more efficient in fixing nitrogen would need less nitrogenous fertilizer, reducing the contribution of fertilizers to greenhouse gas emissions and the accelerated eutrophication of waterways.

ACCOMPLISHMENTS AND CHALLENGES FOR OMICS

Omic will not produce a vegetable such as Minnesota Cuke of Veggie Tales fame, but it can provide potential health benefits to consumers, contribute to a stable food and energy supply, help preserve and protect the environment, benefit farmers, and help eliminate world hunger. Omics has furthered our understanding of pesticide biodegradation, and the mechanisms of pesticide resistance and metabolism, leading to the development of more effective and safer pesticides and the identification of biomarkers to determine human and environmental exposures. The increased knowledge and insights gained from plant genomics are leading to unexpected discoveries and conceptual advances in understanding plant biology. The Department of Energy Office of Biological and Environmental Research is a program providing a predictive, systems-level understanding of plants. Through the advances made by omics, large-scale collections of proteins (proteomes), interactions between proteins (interactomes), metabolites (metabolomes), and collections of observable characteristics (phenomes), are enabling a systems biology approach for understanding plants from the single cell to the mature plant not only during development but, importantly, under changing environmental conditions.

Omic has increased our ability to feed a hungry world, particularly populations that live in less than ideal agricultural regions. Regulators, however, are faced with balancing the enthusiasm of researchers, who want their new products to be immediately on the market, with public interest groups and consumers, who urge caution and do not want modern genetically enhanced foods. The U.S. approach for evaluating products from biotechnology is a coordinated, risk-based system to ensure public safety and the continuing development of biotech products. The policy focuses on the product of genetic modification, not the process itself, and considers genetically modified products to be on a continuum with existing products and therefore employs existing statutes for
their review. In short, the regulations are based on proving substantial equivalence. Recalling Burbank’s plant breeding experiments, the terms plumcot and aprilium have both been used for various fruits derived from plum and apricot parents and are considered equivalent. Thus, the concept of substantial equivalence is not new to plant breeding. Prior to commercialization of a transgenic crop, thousands of genes and transformation events are evaluated. In addition to determining the equivalence of the transgenic with a traditional crop, a safety assessment of the gene and protein product is performed. Among other parameters, the performance of the transgenic plant and the environmental impact of its cultivation are also determined. Compositional analysis comparisons between transgenic and traditional crops are an important aspect of the safety and risk assessment process. Compositional analyses can detect unintended changes, which can occur with any genetic manipulation process.

Agricultural researchers must engage the consumers of their research products, particularly as demographics have transitioned away from agriculture in developed countries. This increasing disconnect has brought a renewed consumer interest in food production, which is not always answered by sound science and is often fueled by misconceptions. Ironically, some certified organic brands, whose companies support strict labeling or outright bans on biotech crops, sell certified organic products that were developed using both chemical and nuclear mutagenesis without reference to this genetic manipulation.

Consumer interest in agricultural practices must be addressed with fact and not opinion and must be used to benefit agricultural research for both industrialized and agrarian-based societies, without hindering a hungry world from feeding itself. A systems approach of sound science, social ramifications, and economic considerations is needed for understanding and embracing products of omics research. Sociological implications differ between industrialized and agrarian nations and must be defined and addressed. There need to be close collaborations and cooperation between scientists, regulators, and the public. Many scientists have voiced concerns that their research is not automatically embraced and, unfortunately, blame regulators, while doing little or nothing to educate the public, the potential consumers of their research. Scientists in omics research need to do their part by dispelling opinions with facts. The modification of biological organisms through any process can carry potential safety risks, raising issues that must be defined and addressed in a manner to satisfy consumers. To ensure biosafety, scientific expertise must be applied to the analysis of biotech crops, their progeny, and anticipated environmental interactions for a sound risk assessment, which ironically can be accomplished, in part, with omic studies.

Global organizations have greatly facilitated cooperation among researchers. Both the Human Genome Project and the sequencing of the rice genome were completed earlier than anticipated due to widespread collaborations. Web sites such as www.gmoanswers.com and www.biotechbenefits.croplife.org provide public forums for discussion and vetting information on biotech crops. The importance of a public forum to engage scientists and the public regarding the safety of biotech crops cannot be overemphasized. A recognized center for researching the safety of biotech crops could also provide opportunity for scientists to interact with the public so that informed decisions can be made at all levels of engagement.

We can see that omics can revolutionize agricultural research in many exciting areas and fulfill the National Agricultural Biotechnology Council’s vision for the future of agriculture. The omics pipeline is full of promise including more functional foods, such as tomatoes with high levels of flavonoids to reduce health risks, foods with higher levels of phytosterols to reduce cholesterol, and plants for producing drugs to address specific health issues. Drought-tolerant maize, arsenic-tolerant plants, low- lignin trees for papermaking, longer bananas with a longer shelf life, plants that can fix ambient N₂, and plants with increased bioluminescence to provide lighting are all potentials. Wine with increased resveratrol for the reduction of oxidized lipids in vivo would be welcomed by enophiles. However, silencing the gene responsible for caffeine production in coffee plants may not be so readily embraced, particularly at six o’clock in the morning.

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Notes

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