Genetically Modified Crops

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Editors

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Foreword

To get easy access to food and to improve the productivity of crop plants, humans have used methods of domestication and improvement through selective breeding, based on useful phenotypic traits. It was through the work of Gregor Mendel that we learnt about the genetic basis of plant traits. The first hybrid corn was developed in 1922 by an intelligent breeding strategy. Following the discovery of DNA as the genetic material, the work of a number of groups led to the concept of gene as the unit of DNA that controls a phenotypic character of an organism. And it was in 1973 that Herbert Boyer and Stanley Cohen developed genetic engineering by inserting DNA from one bacterium to another. Around the same time Jeff Schell and Marc Van Montagu discovered that it is due to the transfer of the plasmid DNA of *Agrobacterium tumefaciens* that results in tumor formation in plants. This research was a by-product of curiosity-driven science and based on fundamental scientific discovery. Using this information and developing plant transformation technology, the group of Mary-Dell Chilton and R. Fraley and scientists from Monsanto Company created the first transgenic plant. During the mid-1990s, with the creation of GM tomato, the initial wave of GM plants was set in motion. However, due to certain issues of public acceptability and stringent regulatory laws that were put in place in different countries, the growth of this technology was slowed down. Van Montagu, whom I have had the pleasure of meeting and knowing for a long time, wrote an insightful article in the *Annual Review of Plant Biology* in 2011 titled, “It is a long way to GM agriculture.” Even then this technology has been used in many crops, and the global biotech crop area is steadily increasing within many countries which have adopted this technology for crop improvement in their agriculture systems. Unfortunately, due to various social and political issues the adoption of this technology has received resistance. This trend needs to be reversed. In the meanwhile, one has seen the emergence of new technologies like RNAi to silence the expression of genes to understand their role as also to develop novel transgenic plants with useful traits. And since 2015, gene editing technologies have evolved which have become useful and efficient tools to manipulate DNA in plant cells. And now we are moving onwards to precision genome engineering through prime genome editing, which does not involve double-strand breaks and donor DNA templates. Hopefully, these interventions will not be subjected to as much stringent regulatory procedures and will also find better acceptability in the society.

An article was published in *EMBO Reports* by Fagerstrom et al. in 2013, entitled "Stop Worrying Start Growing" with the subtitle, "Risk research on GM crops is a dead parrot: it is time to start reaping the benefits of GM." This is even more true today. The present volumes by Professors Kavi Kishor, Rajam, and Pullaiah have been compiled to convey the same message by presenting achievements and opportunity of employing different technological tools for genetic improvement of plants. I have known the editors of this volume for a long time. They have themselves made significant contributions in the area of plant biotechnology and are well acquainted with GMOs, in all its perspectives. They are also aware of the views of opponents of this technology. Accordingly, taking these into considerations, they have broadly outlined the status, prospects, and challenges of different genetic interventions in various plants of economic importance for improving traits like developing resistance to viral, insect, and other diseases and for conferring tolerance to abiotic stresses. With rapid advancements in genome sequencing methodologies and functional genomics tools, it has now been possible to identify the genes that can be deployed in a very precise manner using efficient transformation techniques.

These volumes cover, among cereals, a chapter on rice that deals with the use of GM technology to address the problem of food and nutrition security and a chapter each on wheat and finger millet. Legumes, which remained recalcitrant for a long time and an efficient transformation system was not available, have now been tamed. This family of plants have received special attention, and a chapter each on pigeonpea, chickpea, cowpea, and peanut has found a place in this volume. Among vegetables there is a detailed account on the present status on brinjal, tomato, and cucurbits and one chapter each on redpepper and capsicum. Other plants of importance which have been included are sugarcane, cassava, banana, papaya, citrus, mulberry, and jatropha. The work on two oil plants, sunflower and safflower, has been presented in two independent chapters. This approach of illustrating the use of the technology for each species separately, rather than group them on specific trait, I find, provides a better perspective to evaluate the importance of GM technology with respect to each plant species.

These volumes, I am very sure, will be useful to all students and practitioners of biotechnology, be in colleges, universities, and private organizations, as well as for policy makers and regulators in the government agencies. I look forward to the deployment of the safe use of new tools and techniques of genetic manipulation for the improvement of important plants on a large scale in our agriculture and horticulture system. This will help, along with other breeding methodologies, including marker-assisted breeding, to sustain productivity with limited inputs. We hope to see a hunger-free world in the years to come.

International Centre for Genetic Engineering and Biotechnology, New Delhi, India
June 06, 2020

Sudhir K. Sopory

Preface

Plants provide us many essential things in life, including food, feed, cloth, wood, paper, medicinal compounds, industrial products, and most importantly the life-sustaining molecule oxygen to breath. Plants are also crucial to clean lifesaving water. There are only six crop plants, *viz*., rice, wheat, corn, potato, sweet potato, and cassava, which provide about 80% calories to humans. There are other important crops like sugarcane, barley, sorghum, bean, soybean, coconut, and banana, which are also being consumed by humans. But crop plants are vulnerable to various biotic factors (pathogens and pests) and extreme environmental conditions or abiotic stresses (e.g., high salinity, drought, heat and cold, heavy metals, and submergence) because of their sessile nature. These stresses cause a colossal loss of crop yields and impair nutritional quality. Otherwise, one can realize the potential and harvest 100% agricultural productivity from all crops. In addition, global warming, shrinking water resources, arable land, and population growth are aggravating the problem of food security. In fact, these are key scientific issues in agriculture besides post-harvest losses and impairment in nutritional quality. Then the critical question that arises in our minds is how to harness the full yield potentials of crops without compromising the quality component. The answer lies evidently in the exploitation of diverse technologies, particularly plant breeding and genetic engineering. Between plant breeding and genetic engineering, the former has contributed significantly for more than seven decades to crop improvement and in fact almost all the new and improved varieties were virtually derived through breeding strategies. However, breeding methods suffer from certain limitations like incompatibility barriers or narrow mobilization of useful genes between closely related species. This leads to the problem of using only limited gene pool and there is no way to transfer a single beneficial gene since we generally transfer a cluster of genes/chromosomes during the crosses, thus subjecting F_1 hybrids for 4–5 backcrosses to chuck away the unacceptable. It takes nearly 10–12 years to develop a new variety with desirable traits and may not be cost-effective. In contrast, genetic transformation by *Agrobacterium* or other gene delivery systems or transgenic technology offers several advantages such as precise gene transfer from any source to crop plants. This means a huge gene pool exists for the transfer of desirable traits across species and takes relatively 7–9 years to develop a transgenic line of interest. Consequently, genetic engineering holds great promise for crop improvement and is essential since huge gap exists between food production and rate of population growth. Today's world population is about 7.7 billion and is expected to reach 9.7 billion by 2050, and further to an estimated 11 billion by 2100. Human hunger and malnutrition are the major problems, especially in Asian countries due to accelerating birth rates. So, it is a challenge for plant biologists and biotechnologists to resolve the problem of human hunger and malnutrition through crop improvement programs. In reality, about 70% increase in food production is required by 2050 to feed the growing masses; otherwise we may face great famines in the near future. Indeed, this suggests that a second green revolution is the need of the hour to bring food security to the world population, and this can only happen if we couple the conventional breeding strategies with genetic engineering technologies.

Transgenic technology has already proven to be novel and a potential alternative for crop improvement, and a handful of transgenic varieties like cotton, corn, soybean, and canola have been commercialized globally. This has led to a substantial increase in crop yield and quality, reduced use of harmful pesticides, reduction in CO_2 emissions, and decrease in the cost of crop production, besides improving the economy of marginal farmers. The first transgenic variety, *flavr savr*—the slow ripening tomato, was commercialized in 1994 in the USA, and since then there is a steady increase in the adoption of the first generation of genetically modified (GM) crops such as corn, cotton, and soybean for insect resistance, herbicide tolerance, and improvement of oil quality. In 2018, about 475 million acres (191.7 million hectares) of land was under the cultivation of various GM crops in 26 countries (21 developing and 5 developed countries), including 5 top countries—USA, Argentina, Brazil, Canada, and India (with the adoption of only Bt cotton) with the largest area of GM crops grown, and an additional 44 countries imported these GM crops. To date, about 525 different transgenic events in 32 crops have been approved for cultivation in different parts of the world. Currently, the next generation of transgenic plants displayed potential for the production of bio-ethanol, bio-plastics, and many pharmaceutically important recombinant proteins and compounds. Interestingly, the recent genome engineering or editing technology is quickly gaining importance for maneuvering genes in crop plants using the gene editing tool, the CRISPR-Cas system. This technology is aiding us in the improvement of many agronomically important traits such as yield, stress tolerance, and nutritional quality. Soon, the gene-edited crop plants with new traits, but not having an alien gene, will be commercialized. Such an endeavor will assist us in meeting the increasing food demands and global food security. This technology can be safely exploited since it has minimum or no regulatory issues. GM crops have the most rapid adoption rate in the history in spite of public concerns as compared to the traditional hybrids like corn, which took more than seven decades for global penetration. Transgenic varieties were released only after passing the tests against environmental aggressiveness, toxicity, allergenicity, after fulfilling the stringent regulatory guidelines laid down by the respective countries, and after exhibiting their superiority for field performance vis-à-vis the untransformed or wild-type plants.

The present book brought in two volumes has updated information about the current status of GM crops. While the first volume covered genetic modification studies in cereals, pulses, and oil-yielding crops, the second one included information on important vegetable, fruit-yielding, and commercial crops. These volumes on GM crops will be handy to students of life science stream of both undergraduate and postgraduate studies, research scholars, postdocs and researchers working in plant and agricultural biotechnology organizations, faculty members, biotech companies, and professionals alike.

Lastly, we would like to express our heartfelt gratitude to Springer-Singapore for kindly consenting to bring out this book in two volumes and for extending support through various phases and for the timely completion of publishing. Our heartfelt thanks are also due to Prof. Sudhir K. Sopory, ICGEB, New Delhi, for writing the foreword. We would like to thank all the authors/coauthors who have contributed the review articles and also for their cooperation and erudition.

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T. Pullaiah is a former Professor in the Department of Botany at Sri Krishnadevaraya University in Andhra Pradesh, India. He has held several positions at the university and was President of the Indian Botanical Society and of the Indian Association for Angiosperm Taxonomy. He holds a PhD from Andhra University, India, and was a Postdoctoral Fellow at Moscow State University, Russia.

He was awarded the Panchanan Maheshwari Gold Medal, the Dr. G. Panigrahi Memorial Lecture award of the Indian Botanical Society, and the Prof. Y.D. Tyagi Gold Medal of the Indian Association for Angiosperm Taxonomy. He has authored 51 books, edited 19 books, and published over 330 research papers. He was a member of the Species Survival Commission of the International Union for Conservation of Nature (IUCN).