CROP IMPROVEMENT (THE "GENE" REVOLUTION)

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Summary

The beginning of crop improvement likely occurred when plants were first domesticated and growers selected seeds from plants with desirable characteristics to grow in the following seasons. With the advancements made in areas such as genetics, biotechnology, engineering and agriculture, the generation of higher yielding crops has become much more sophisticated. The tools that are now available to farmers and researchers to develop genetically modified crops with improved characteristics to overcome abiotic and biotic stresses would likely have been unimaginable to our earliest ancestors. As the global population continues to expand and the arable land area continues to decrease, the need for the production of large quantities of high quality and nutritious foods has become of paramount importance. When there was a similar need to significantly increase food production following the Second World War, farmers and scientists around the world collectively introduced revolutionary changes to agronomic practices that ultimately led to the generation of high yielding semi-dwarf varieties of wheat and rice. This green revolution was instrumental in allowing developing countries such as India to produce sufficient quantities of food to, not only feed its own

population, but also to export excess grain to other countries in need. The green revolution likely prevented the deaths of millions due to widespread starvation. As successful as the green revolution was, it can be argued that there is a need for another agricultural revolution to further increase global food production. This encyclopedia chapter discusses the important events that led to the green revolution and how gene revolution for crop improvement has developed from the use of genetic engineering to modify crops to deal with environmental stresses and disease-causing organisms. Notable examples of genetically engineered crops that have already had a significant impact on agriculture include Bt-transgenic plants, “Golden Rice” and virus-resistant papaya.

1. Introduction

1.1. The Origin of Agriculture and Agricultural Revolutions

Although agriculture, in the broadest sense, can be thought of as the sum of all of the processes involved in farming, including crop production and raising of livestock, this encyclopedia chapter will focus on the application of genetic engineering to improve crop production in terms of quality and yield. It is believed that humans domesticated plants throughout the world in at least eight independent or "pristine" centers (although different authors recognize between 8 to 12 independent centers), namely, (a) Asia (Near East, South China, North China), (b) the Americas (South America, Central Mexico, Eastern United States), (c) Africa (Sub-Sahara) and (d) the Western Pacific (New Guinea). It is believed that agriculture developed as part of a natural process of cultural evolution and spread widely from these primary centers. The first agricultural revolution, which started around 8 000 BC is also known as the Neolithic Revolution. From the beginning, the practice of agriculture has taken advantage of the naturally-occurring fundamental processes of energy and nutrient transfers that characterize natural ecosystems, and humans have harnessed these processes to develop agroecosystems.

Maintaining viable and sustainable agricultural productivity is crucial in order to continue to provide sufficient food to feed the rapidly growing global population. Throughout history, farmers have utilized technology in an effort to significantly improve food production. Plant breeding techniques have been used to create new varieties of crops adapted to specific environments or needs, including those that are resistant to environmental stresses or are easier to harvest. In addition, chemical input in the form of pesticides and herbicides are widely used to protect crops from insects, pathogens and weeds. Fertilizers are routinely used to replenish nutrients in the soil that are required for optimal growth and development thus ensuring high productivity of our crop plants. During the past 50 years, plant breeders have succeeded in generating high yielding cultivars of plants with a seemingly ideal complement of genes, which are often sourced from different wild populations, to develop crops that exhibit desired characteristics. All these advances in crop agriculture, collectively referred to as the green revolution, or as the second agricultural revolution, have been credited for significantly increasing agricultural productivity around the world. However, the growing population coupled with a dwindling land base for agriculture has necessitated the development of novel crop varieties with even higher yield potential. To this end, a

third revolution in crop agriculture, the gene revolution is occurring at this time which has significant potential to improve the tolerance of crop varieties to environmental stresses, pathogens, and insects that severely affect productivity. In addition, this gene revolution has the potential to develop designer crops with increased nutritive value such as "Golden Rice" for combating vitamin A deficiency in large parts of the world.

2. The Green Revolution

2.1. Historical Perspectives

The term green revolution was first used to describe the land reforms that took place in Eastern Europe during the 1930s, but this term is now perhaps more commonly used to describe a revolution in agriculture that occurred during the 1950s and 1960s. Following the Second World War, countries in the southern regions of Asia encountered a significant population increase, which may have contributed to a rise in poverty levels and food shortages. Yields of wheat and rice were relatively low due to primitive agricultural practices including the use of crop varieties that were only suitable for local micro-environments thereby limiting the area in which a particular variety could be grown. The introduction of high yielding crop varieties (HYV), developed by Dr. Norman Borlaug and the Rockefeller Foundation, adoption of modern agricultural practices involving the use of chemical fertilizers, pesticides and the mechanization of agriculture led to dramatic improvements in crop productivity in various parts of the world. Thus the green revolution led to the increased availability of food thereby preventing catastrophic and widespread malnutrition. In March 1968, William Gaud, a United States Agency for International Development (USAID) Administrator, speaking to the Society for International Development in Washington emphasized that the changes that took place in the wheat and rice fields of Asia were revolutionary, albeit non-violent, and termed it the green revolution. Dr. Norman Borlaug, widely believed to be the father of this green revolution was awarded the Nobel Peace Prize in 1970 for his contributions to humanity.

2.2. The Generation of High Yielding Varieties (HYV)

The success of the green revolution can be largely attributed to the introduction of high-yielding semi-dwarf varieties of wheat and rice along with the application of large amounts of nitrogen fertilizers. The use of nitrogen fertilizers was essential to increase the yield of grains; however, it also promoted stem elongation, which resulted in an overall increase in plant height. The stems of tall wheat and rice plants were not strong enough to support the heavy grain of the HYVs so these plants would "lodge" or fall over. The development and introduction of semi-dwarf cereal crop varieties, which would not lodge during crop production, was therefore crucial for the success of the green revolution.

Semi-dwarf wheat originated in Japan during the late 19th century when Japanese researchers hybridized the Daruma variety of wheat with several American varieties ultimately giving rise to an extremely productive variety of wheat they named Norin 10. Scientists in the United States then crossed Norin 10 with a native variety called Brevor and took the product of this cross to Mexico in 1954 where Dr. Norman Borlaug and his

colleagues developed several HYVs of wheat. The seeds from the semi-dwarf HYV plants that were generated were subsequently sent to India and other developing countries.

The generation of semi-dwarf rice paralleled the development of semi-dwarf wheat. The dwarfing gene was identified from a Chinese rice variety called *Dee-geo-woo-gen*, which was used to produce a highly successful Taichung Native-1 (TN-1) variety through a breeding program in Taiwan. A cross between *Dee-geo-woo-gen* and an Indonesian variety named *Peta*, at the International Rice Research Institute (IRRI), Philippines, resulted in the generation of a semi-dwarf rice variety named IR-8. Many commercial semi-dwarf *indica* cultivars grown in tropical and semi-tropical areas have subsequently been generated from TN-1 and IR-8. Semi-dwarf HYVs have also been produced independently in China, Japan and the USA. The green revolution in rice was dependent on the introduction of semi-dwarf, high yielding *indica* cultivars grown in tropical areas. In comparison to the traditional crops, these HYVs planted on irrigated land with the use of chemical fertilizers and pesticide gave higher yields per unit of land area and greater profits to farmers. New rice varieties transformed flood-prone land to areas that rice growers could now utilize and increased production to levels five times greater than traditional deepwater varieties. Due to the green revolution, the HYVs of wheat and rice are now planted on 84 and 74% of farmed land, respectively, irrigation has increased more than two-fold, fertilizer consumption has increased more than 30-fold and as a result, rice and wheat production has increased from 127 million tons to over 760 million tons between the 1960s and 2000.

2.3. The Spread of the Green Revolution

Even though the green revolution first began in Mexico (1950s), the precursors to this revolution could be traced to the significant increase in productivity observed in hybrid maize experienced by US farmers during the 1930s and the 1940s. The green revolution then spread from Mexico to India (1950s), Pakistan and the Philippines (1960 to 1970s) and later to China (1980). During the mid-1960s to the early 2000s, a number of other countries such as Afghanistan, Indonesia, Iran, Kenya, Malaysia, Morocco, Sri Lanka, Thailand, Tunisia and Turkey have also adopted the use of HYVs and have reaped the benefits associated with improved agricultural practices, plant protection measures, chemicals, fertilizers and mechanization. However, as Gordon Conway, an expert on the green revolution, points out in his book, "The Doubly Green Revolution", the practices that made the green revolution successful in various parts of the world has been somewhat of a hit-or-miss in some other parts of the world. Despite this, it can be argued that any increased productivity achieved from the green revolution was not merely a one-time increase in crop yields, but rather a long-term and sustainable one.

2.4. Success of the Green Revolution in India

During the 1950s, soon after its independence from Great Britain, India was in the midst of dealing with problems arising from its limited agricultural productivity and there were many who believed that India would not be able to feed its population. However, the introduction of HYVs developed in Mexico, into India increased the yields of cereal crops two- to three-fold in the Punjab region alone. This "miracle" seed brought new

hope for sustainable agriculture on the Indian subcontinent and the use of the HYVs quickly spread to neighboring regions. The Ford Foundation and the Indian government collaborated to import a significant amount of wheat seeds from The International Maize and Wheat Improvement Center (CIMMYT), Mexico for Indian farmers to grow on their fields. Soon after, India began its own green revolution through plant breeding, development of irrigation systems as well as the development and use of agrochemicals (fertilizers and pest control agents). The higher yield and greater profits achieved due to the use of HYVs of wheat led to greater adoption of these varieties by farmers. As a result, the total cereal production in India increased from an annual average of 74 million metric tons in the 1960s to 100 million metric tons in the 1980s and to 134 million metric tons by the 1990s. The green revolution was instrumental in helping transform India from a country that relied on food imports to help feed its population to a self-sufficient nation whose crop production was high enough that it could export excess grain to other nations. It also played a significant role in boosting overall economic growth by raising the incomes of farmers and increasing the pace and volume of trade and commerce. The success of the green revolution in India is an example of how the cooperation between various agencies and governments led to the implementation of agricultural practices that improved productivity and brought prosperity to regions that could not feed their population at one instance.

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Biographical Sketches

Nat N. V. Kav, Ph.D.(Associate Professor) Originally from India, Dr. Nat Kav received a PhD (Biochemistry) from the University of Calgary. After working in various research facilities, including in private industry, Dr. Kav became a faculty member at the University of Alberta where he is currently an Associate Professor in the Department of Agricultural, Food and Nutritional Science. His research interests include the application of proteomics, genomics and biotechnology to study the effects of abiotic and biotic factors on plants. The discovery and validation of proteins and genes affected by abiotic and biotic stresses may lead to crop improvement through the use of genetic engineering. Dr. Kav is also one of the principal investigators of a prion research project that is interested in elucidating the structure and function of prion proteins. Dr. Kav has presented at many national and international scientific meetings and has published numerous manuscripts in peer-reviewed scientific journals.

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