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# THE APPLICATION OF MUTAGENESIS IN PLANT BREEDING UNDER CLIMATE CHANGE

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**Abstract:** *The purpose of mutation induction is to accelerate the rate of mutation during the emergence of new plant species. Since spontaneous mutations are uncommon, it is challenging to employ them in plant breeding. Previously, physical (such as gamma radiation) and chemical (such as ethyl methane sulphate) mutagen treatments were employed to produce mutations in seeds and vegetatively propagated crops. Plant mutagenesis maturation has been accelerated by recent developments in high-resolution molecular and biochemical techniques. Characteristics that are virtually impossible to identify through conventional breeding are developed and molecularly defined using a large number of mutant populations and innovative screening tools. The numerous methods and techniques that molecular breeding researchers have access to at the moment are fully summarized on this page, along with how these resources complement those used in traditional breeding. TILLING (Targeting Induced Local Lesions in Genomes) and phenotypic screening are used in the evaluations. The genetic-phenotype gap can be closed using a variety of methods, which are discussed in the conclusion.*

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## Introduction

During the Neolithic Revolution, when hunter-gatherer tribes became sedentary and agricultural, plant breeding began around 10,000 B.C. During this historical period, various subtropical regions, including central Africa, western South America, Southeast Asia, and the Mediterranean, domesticated crop plants. Although cave paintings in Lascaux, France, and Altamira, Spain indicate that prehistoric man was aware of the environment and the life cycle, it is unknown if the earliest attempts at domestication were deliberate or accidental (Bado et al., 2015). Despite the significant impact of plant breeding on agricultural productivity, the earliest attempts at plant breeding were likely limited to choosing the healthiest individuals from each harvest for later sowing (Pathirana, 2011). As a result of constant human interactions with the environment, natural selection has dramatically impacted plant life. Charles Darwin coined the term "artificial selection" in 1859 to distinguish between natural and artificial selection, as domesticated plants can never be regarded "natural." In a second study, published in 1868, he then dug into further depth. Domesticated plants have evolved to the point that they are frequently believed to be separate species from their wild counterparts as a result of systematic selection (Gottschalk & Wolff, 2012). These civilizations were able to expand, specialize in occupations other than food production, and raise population density due to better grain harvests. Increased trade and population density caused by the transition from foraging to agriculture resulted in the emergence of new infectious diseases and epidemics, as well as a reduction in the food diversity available to humans. On the other hand, plant breeding could be considered the cornerstone of our modern civilization (Shu et al., 2012).

Both tilling and mutation are processes. Throughout agricultural history, breeders have prioritized "elite" cultivars, reducing genetic variety. In response to genetic degeneration, which eventually reached a bottleneck in the middle of the previous century, several technologies to manufacture mutations artificially and increase variation were developed (Shu et al., 2012). Initially, X-ray radiation was utilized as a mutagen due to its simplicity of application. Stadler discovered that when barley seedlings were exposed to X-rays and radium, maize tassels generated significant phenotypic variation and sterility. Muller discovered in 1927 that exposing Drosophila to X-rays increased the mutation rate by 150 percent. Radiation techniques, including gamma and neutron, were subsequently developed by new nuclear research centres. During and after World War II, chemical mutagens were used in conjunction with radiation-based treatments because they were safer, more widely available, and easier to employ. Auerbach and colleagues conducted the first study to demonstrate that exposure to mustard gas increased the frequency of mutations in Drosophila (War Gas). Shortly thereafter, methane sulphonates and other chemical mutagens still in use today were found (Broertjes & Van Harten, 2013).

Utilizing crop genetic engineering to address global food security and nutrition challenges is necessary. To meet the needs of a rapidly growing population, food production is anticipated to more than triple by 2050. A heritable variation must exist before plants can be genetically changed (Raina et al., 2016). Where natural diversity is in little supply, artificial diversity can be created. Excluding recombination, chemical or physical mutagens are the most often described way for developing unique variants in plant components. Because the site of DNA lesions cannot be reliably predicted in advance, irradiation and chemical mutagenesis are typically referred to as random mutagenesis, despite the fact that different mutagens have diverse effects on plant genomes and some positional biases have been identified. Depending on the type and concentration of the mutagen, various impacts on the DNA sequence are observed. Once sufficient genetic variation has been generated, the subsequent step is to pick materials with the desired modified properties(Bradshaw, 2017).

**Repercussions of climate change on agricultural practices**

It is impossible to overestimate the significance of resources, climate, and environment in agriculture. As a result of industrialization and population increase, more stress is being placed on water resources, arable land, the environment, germplasm resources, and sustainable forestry practices. The rise in food costs and its negative effects on global food production are indisputable facts (Broertjes, 2012). The effects of climatic changes such as gaseous pollution, ozone loss in the atmosphere, increase in UV-B radiation, increase in atmospheric $CO_2$, extreme variability of rainfall time and location, irregular lengths of growing seasons, intermittent dry spells, global warming, high temperatures, and degradation of water and soil resources may be significant contributors to this problem. Moreover, planners face challenges in overcoming complex inherent uncertainties such as our inability to predict the rate, nature, and extent of climatic change, especially rainfall patterns, the threat of irreversible ecosystem damage, a very long planning horizon, long time lags between greenhouse gas emissions and climate effects, wide regional variation in causes and effects, the global scope of the problem, and the need to mitigate climate change(Araki & Ishii, 2015). As a result of global warming, the emergence of new pests, diseases, and insects, as well as the extinction of some already existing ones, may have a significant impact on agricultural production. Changes in growth rates, the emergence of weeds and insect pests, and the resulting effects on agricultural output are all the result of growing $CO_2$ levels in the atmosphere and the threat of global climate change. Increased $CO_2$ concentrations may accelerate plant growth, hence reducing competition between cultivated and weedy plants. Cotton appears to be more sensitive to rising $CO_2$ levels than wheat. In response to increased UV-B radiation exposure, the spectral domain of leaves alters due to structural and pigmentary alterations (Breseghello & Coelho, 2013). This is because the structure, surface reflectance, and pigments have changed. Moreover, a drop in stratospheric ozone may be detrimental to Earth's life due to an increase in UV-B radiation reaching the planet. Alone or in combination with other pollutants, ambient ozone levels reduce crop yields of a variety of essential crops(Hartung & Schiemann, 2014).

**Adaptation strategies in response to changing climatic conditions**

Climate change is putting pressure on agronomists and plant breeders to protect the food supply. Both industrialized and developing countries are already experiencing economic hardship as a result of rising food and gasoline prices (Hartung & Schiemann, 2014). The world food crisis won't be solved in the near future, despite the fact that the poorest countries are currently in the greatest economic suffering. Identify the most efficient and cost-effective ways to maintain food production (Shao et al., 2011). In order to create novel cultivars that may be able to withstand cyclical climate fluctuations, conventional breeding is combined with alternative technologies like mutagenesis, biotechnology, genetic engineering, and molecular breeding. This is done because targeted breeding variants might not be effective in this regard (Lundqvist et al., 2012; Oladosu et al., 2016).

**Mutation breeding**

One of the key advantages of mutation breeding is discovering mutants with diverse features. Mutant variations have a significantly greater probability of surviving in environments that are constantly changing. Prior to the discovery of new cost-effective, widely accessible, and everlasting methods, I believe that utilizing nuclear technology is the optimal strategy for generating new sorts in response to climate change. Despite advances in transgenic research for single-gene traits, numerous fields of molecular biology and transgenic research remain in the experimental phase (Mba, 2013).

**Goal of mutagenesis**

Breeding based on mutagenesis attempts to increase genetic diversity while lowering viability loss. Fast neutron and -ray bombardment now outperforms X-ray in the majority of radiation-based applications. Fast neutron bombardment causes translocations, chromosome losses, and massive deletions, whereas -ray bombardment causes point mutations and minute deletions. Both forms of radiation significantly diminish viability and cause more damage than chemical mutagens(Forster & Shu, 2012).

**Mutation induction methods**

**Physical mutagens**

Over 90% of all direct mutant variations are produced through radiation-induced mutation induction (64% with gamma rays and 22% with X-rays). Ionizing radiation (IR) and ultraviolet radiation are the two types of radiation capable of inducing mutagenesis (UV). Ultraviolet light (250-290 nm) penetrates tissue less effectively than ionizing radiation (Hayward et al., 2012).

**Ion beam technology**

Heavy ion beam (HIB) is used as a new physical mutagen instead of gamma rays, X-rays and neutrons, which has been predominantly used for mutation induction in plants (26,27,28). These beams are responsible for linear energy transfer (LET) and as LET increases that induces higher biological effects such as lethality, chromosomal aberration etc., as compared to most commonly used physical mutagens (Suprasanna et al., 2015).

**Chemical mutagens**

Chemical agents are advantageous due to their high mutation rates, the majority of which are point mutations. Alkylating agents such as ethyl methane sulphonate (EMS), diethyl sulphate (dES), ethyleneimine (EI), ethyl nitroso urethane (ENU), ethyl nitroso urea (ENH), and methyl nitroso urea (MNH), as well as azides, are the chemical mutagens most commonly used to induce mutations(Murovec & Bohanec, 2011).

**Induced Mutation Process Led to the Development of Superior Genotypes**

Plant breeders started using the ability to cause mutations to create new kinds as soon as Drosophila and cereal research revealed it. The first instance was the tobacco mutant "Chlorina," which was created in the 1930s by exposing flower buds to X-rays. The International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations (Joint FAO/IAEA) manage the Mutant Varieties Database in Vienna, Austria. More than 3,220 crop types that were developed by induced mutations and are now grown all over the world are available in its searchable database. Cereals make up more than half (48%) of crop kinds grown from seed(Podevin et al., 2013).

**Detection of Unusual Characteristics in Genetically Altered Populations**

**Phenotypic Screening**

Agriculture began more than 10,000 years ago in the Fertile Crescent, where the first crops were grown. The forefathers of today's hunters and gatherers made the earliest attempts at plant breeding, identifying (phenotyping) and purposely selecting off-type species. Wheat, barley, millet, and emmer are regarded to be the first domesticated plants. In the species picked by first-generation phenotypists, larger grains and fewer broken seeds were preferred. They developed new crops without knowing why or whether the chosen mutations were heritable(Ashri & Janick, 2010). Around 300 B.C., the selection of plants with unusual yet great characteristics was chronicled in the ancient Chinese literature "Lulan." These are the earliest examples of mutant selection, which most likely happened by chance. The number of days until maturity and other easily seen features of grain harvests were among the factors that had been improved. Hugo de Vries used the term "mutation" much later to denote a large, multigenerational genetic change in higher plants. Although induced mutations are routinely used to introduce novel kinds into crop species, years of intense breeding have reduced the genetic diversity of many crop species, making spontaneous mutations an important source of variation(Veilleux, 2011).

**Biochemical screening**

The fundamental objective of TILLING is to enable the detection of genetic alterations. This does not prohibit phenotypic screening using TILLING and other mutant populations(Kolchanov et al., 2017).

**Physiological Screening**

Infectious fungus pose a hazard to world agriculture. Global climate change, which will result in milder winters and greater humidity, is anticipated to exacerbate the problem. Fusarium is a virulent pathogen that is widespread in Europe, North America, and Scandinavia(Germana, 2011). Important agricultural crops, such as oats, wheat, barley, and corn, are infected by Fusarium, a fungus with over a thousand varieties. In addition, Fusarium sp. creates a variety of mycotoxins that build in grain, enter the food chain, and damage the health of both humans and animals. Fungicide treatments can aggravate mycotoxin contamination because there are no viable management alternatives for FHB at present. Unfortunately, breeding populations lack the genetic diversity necessary to find and produce disease-resistant strains(Penna & Jain, 2017).

**Agricultural progress in the face of climate change**

The majority of cultivars of staple crops no longer match the criteria for a highly efficient, low-input crop production system. This involves the development of a new portfolio of crop plant varieties. By producing mutations in crops, scientists are able to establish fundamental genic controls that impact the expression of agronomic and crop features. Scientists' understanding and ability to do so have vastly increased. In functional genomics, induced mutagenesis is a frequently employed technique because it simplifies the finding of genes and the comprehension of their functions. The functional genomics output of the discovered genes improved plant performance when utilised as molecular genetic markers. In addition to chemical and physical mutagenesis, scientists combine chemical and physical mutagens and TILLING with mutagenesis more frequently. This chapter describes how to use physical and chemical mutagenesis techniques to create plant genotypes with desirable features(Saif-u-Malook et al., 2015; Vasline & Sabesan, 2011). Researchers are developing the most efficient and suitable methods for producing the necessary genotypes. Nevertheless, it seems doubtful that in the future customers will accept transgenic foods as "normal." Somaclonal changes may be a more accurate predictor of favourable traits at an early stage. Popular in the mid-twentieth century induced mutagenesis technologies should be researched further and improved in a variety of ways for plant development in the twenty-first century(Lusser & Davies, 2013). It is more necessary to choose plants with the proper traits than to employ production tactics such as mutation or variety. As a result, there are several opportunities for the application of molecular probes in this field. In mutagenesis processes, probe-based molecular approaches will become increasingly significant, particularly for altering superior agricultural plant traits for industrial processing, such as protein, starch, and oil. Mutation requires just trace amounts of tissues and calli; once standard technologies for these operations are in place, this quantity might be decreased to micrograms. Using in vitro growing techniques, the quantity of produced material was reduced to a milligramme(Hake & Ross-Ibarra, 2015). Few plants, like sugarcane and bananas, are mutagenic and can be reproduced vegetatively in vitro. Utilizing cell suspension culture, seeds such as corn, barley, soybeans, rice, wheat, and rapeseed are propagated (Hirano et al., 2015). Despite substantial restrictions, such as cell clumping in suspension culture, it is anticipated that the irradiation dose necessary to induce mutation in cell suspension culture will be less than in callus culture. Therefore, we should prepare for developments in vegetative and seed propagation techniques. Methods for creating and utilizing in vitro selection media for disease- and toxin-resistant cells are also feasible (Rauf et al., 2010).

**Conclusion**

Plant breeders rely on induced mutations to maintain genetic diversity since spontaneous mutations happen so infrequently that they cannot be used. The ability to recover mutants with a variety of traits is the key benefit of induced mutations over transgenic procedures, which only allow the introduction of a single feature into a crop. Moreover, it is difficult to get people to accept genetically engineered food. Benefits of mutation induction include the creation of various mutant lines, the identification of genes that are specific to traits, the study of molecular functional genomics, and the advancement of bioinformatics for the creation of plant varieties that can be grown on available arable land despite climate change in order to feed a rapidly growing human population. Furthermore, one advantage of mutagenesis is the discovery of mutants with a range of traits that, in theory, give them the best chance of surviving in a changing environment.

The genetic variation accessible to plant breeders can be increased via mutagenesis in conjunction with plant tissue culture and the length of the culture phase, particularly in cereals. It may be used more frequently before genetic engineering becomes a standard and reliable tool in plant breeding. The population-growing developing world cannot wait for genetic engineering to deliver massive yields. Tissue culture and mutagenesis are currently tools that plant breeders can utilise to encourage genetic variation.

**Conflict of interest**

The authors declared absence of conflict of interest.

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