Genomics: Usage of Radiation to Perform Mutation Breeding

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I. Brief Description

Mutation breeding was first publicized in the 1920s. In 1927, Hermann J. Muller, an American geneticist, had discovered the effect of X-ray to gene structures by causing it to produce mutations and undergo chromosome changes, which was proven true during a group study conducted on the influence of mutation frequency to fruit flies. Another geneticist named Lewis Stadler published his research about the mutations of crop plants, such as barley and maize, after being exposed to radiation. Both researchers have paved the way to current breeding procedures utilized in agriculture and possibly, future methods of mutation breeding.

Mutation breeding is the use of a plant's own genetic make-up to mimic the natural process of spontaneous mutation. It is used to accelerate the process of developing and selecting new valuable agronomic traits; through this new mutant plants are made with new and useful traits (Tarakanov, 2022).

Currently, this method of breeding can be done through chemical or physical methods. These methods can either use radiation such as those from Gamma rays and X-rays, or through a newer method called "particle breeding" which uses charged particles that may be in the form of a heavy ion or proton (Ma et al., 2021).

Mutation breeding is a method that shares the same objective of traditional crop breeding which is to create plants with improved characteristics that are desirable, however these methods differ in the process of producing such crops. According to Crop Science (n.d), traditional methods such as classical, cross, and introgression breeding rely on the traits of two plants and combine them either through breeding them naturally, adding a specific strip of DNA into the plant's genome, or backcrossing. Meanwhile, mutation breeding like classic, particle, and space radiation breeding directly or indirectly alters a plant's genetic makeup without introducing new genetic material (Ma et al., 2021). Furthermore, unlike typical breeding methods, mutation breeding creates mutations that may be unstable thus limiting the process of generating the preferable alleles. However, mutation breeding can be used as a way to identify what would be the best trait to amplify in a plant and using other methods such as introgression breeding to

be able to recreate that amplified trait and create more plants with DNA carrying such traits.

Due to the tendency of random mutations, mutation breeding is found to be essential in creating diverse traits in plants. It is also a key tool used for identifying regulatory genes and molecular mechanisms, and studying the evolution of animals' relationships and genetic makeup. These show that mutation breeding is an important factor in modern technology as a means of efficient food production and source of varying traits.

II. Science Concepts Involved

- **Biology**

According to Gilchrist (n.d.), **Mutations** are "errors" or changes in a living organism's genome which can result in new characteristics that can either be passed on to its offspring or not. However, these mutations are most likely random and assessed to be affected by the organism's environment. Since mutation breeding is done by exposing the plant to radiation with a high-frequency electromagnetic field, it is likely that the radiation will inflict damage and instability to the plant's DNA.

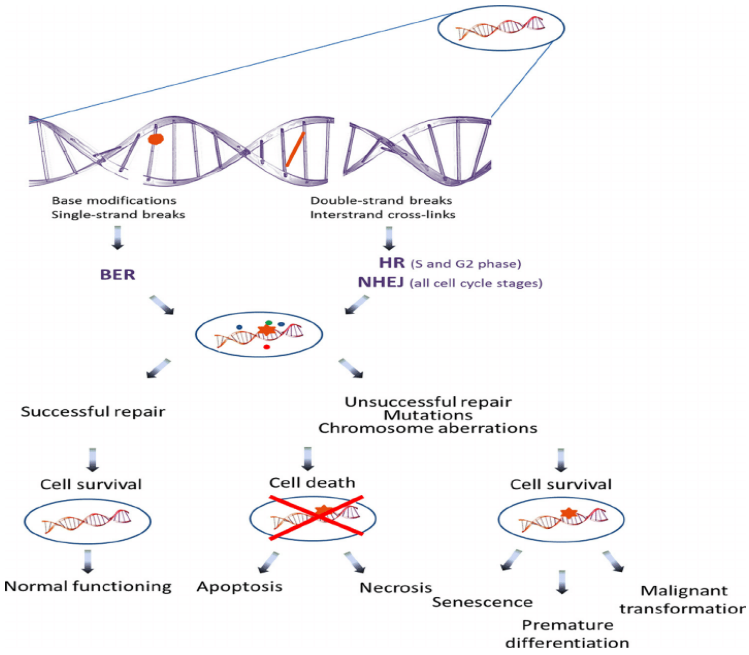

Figure 1 Mutation in cells

Fortunately, plants have developed repair mechanisms in their enzymes such as nucleases, recombinases, polymerases, topoisomerases, kinases, ligases, glycosylases, helicases, phosphatases, and demethylases. (Gimenez & Manzano-Agugliaro, 2017) However, there are instances when these mechanisms are unsuccessful or "make an error" in fixing the damage which results in a mutation of mutagenesis. Mutagenesis is the process by which an organism's DNA changes resulting in gene mutation. (Durland & Ahmadian-Moghadam, 2021)

An example of space radiation breeding where mutagenesis is present would be back in 2014 when a cherry tree in Japan bloomed six years earlier than expected with different flowers after orbiting the Earth for eight months as seeds. When Japanese astronaut Koichi Wakata and the saplings were sent to the ISS, an experiment was conducted on the saplings and once back on earth some of the seeds were planted. This study provided some intriguing results, not only has the tree grown earlier than expected but the tree produced flowers with only five petals compared to the thirty petals found in other trees (Sato, 2014). Moreover, this is an example of space radiation breeding and mutagenesis as there are changes in the physical properties of the cherry tree due to its exposure to an environment outside of the earth resulting in an altered DNA sequence.

- **Chemistry**

Ionization is the process of gaining or losing an electron in an atom or molecule. This turns the atom into an ion that can either have a positive (cation) or negative (anion) charge. In order to move an electron from its position, an input of energy is required (Energy Education, n.d.).

In the case of mutation breeding, ionizing radiation is done to create mutations. This process, otherwise known as irradiation, only consists of removing an electron from its position through application of radiation and breaking chemical bonds that causes damage to the plant's genome structure and mutations to occur. Additionally, it can also speed up the mutating procedure through the particle accelerator, which accelerates charged particles and directs them into a beam, thus making mutation breeding a faster and less demanding method in contrast to conventional ones.

According to the United States Environmental Protection Agency, particle accelerators use electromagnetic fields to push charged particles along a path, making them go almost as fast as light. Magnets then steer the particles at top speed into a target, and when the particles hit the target, the atoms in the target split apart.

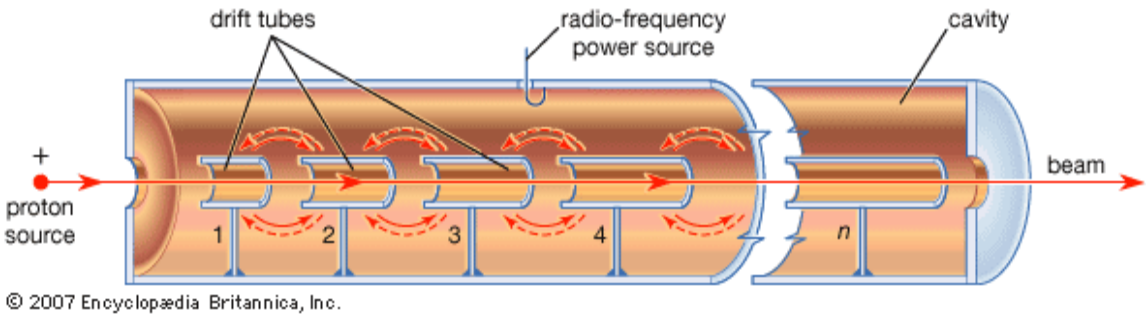

Figure 2 Particle Accelerator

- **Physics**

Based on the Centers for Disease Control and Prevention (n.d.), **Radiation** is a form of energy that can move through waves from one place to another. The different types of radiation are mainly ionizing and non-ionizing radiation which differ in their ability to conduct ionization. In particular, ionizing radiation is the most crucial factor in mutation breeding because it induces a change in the plant's DNA, which then generates mutations.

Ionizing radiation is a form of radiation with a high amount of energy, making it capable of conducting ionization or the removal of electrons from an atom. Due to the missing electrons, this process can alter genetic makeup and inflict damage to the tissue of organisms exposed to it.

Meanwhile, non-ionizing radiation such as radio waves, microwaves, and infrared radiation have low amounts of energy that enables atoms to move but not enough to eject an electron. For its inability to remove electrons, it is less hazardous than ionizing radiation and thus, it is more implemented in medical assessments, like diagnostic imaging, than ionizing radiation since it is less hazardous towards organisms' cells.

Gamma rays and X-rays, the most common type of radiation used in mutation breeding, are examples of ionizing radiation. As this is a form of radiation with a high amount of energy, making it capable of removing electrons from an atom. Due to the missing electrons, this process can alter genetic makeup and inflict damage to the tissue of organisms exposed to it.

III. How to Use the Output

With mutation rates of 1,000 to 1,000,000 fold, the usage of radiation for mutation breeding significantly decreases the time for the plants to evolve and produces massive populations of the new and modified plant. Furthermore, usage of ionizing radiation has shown to be effective with over 3,000 varieties of crops created by it. Since the usage of Gamma radiation is inexpensive and highly effective, it has become a good alternative for genetically modified plants. To add to this, farmers and botanists can incur less expenses when radiation is used for mutation breeding. Mutation breeding can be especially beneficial for them because through it, plants can be modified to withstand harsh growing conditions and diseases, so whether it is drought period or monsoon season, there will still be enough food produced to sell for a living and for their personal means as well. (Tarakanov, 2022).

Overall, mutation breeding has been an efficient method that has existed for the last 100 years and has proven to be beneficial for both producers and consumers. With it, global problems may be resolved, and famine may no longer subside as a global issue in the generations to come.

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