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Induced Mutagenesis in Vegetable crops: A Review

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Abstract

Mutation breeding is the key for developing crop features beyond hybridization capabilities, aiming to create significant genetic diversity. It uses chemical mutagens like EMS and MMS, and physical mutagens such as gamma rays. Advances in genome technology and genomic approaches are shaping its future, especially for crops with limited diversity. This method remains crucial for enhancing vegetable yields, provided it has a clear goal and effective techniques.
Keywords: EMS, gamma rays, MMS, mutation breeding, mutagens.

INTRODUCTION

If we look at the increasing population, we may not be able to provide adequate food to everyone in the upcoming future to a population of 9 billion that is expected by 2050 (Béné *et al.*, 2015). Different techniques of breeding science have always been making a significant contribution to the creation of genetically enhanced agricultural varieties. Principles of plant breeding can be divided into 3 types of breeding systems: Recombination breeding, Transgenic breeding and Mutation breeding and mutation breeding aims at generating variation and selecting new mutated alleles (Shu, 2009). The word mutation is known to be coined by the Dutch botanist and geneticist Hugo de Vries and defined it as sudden, discontinuous, and heritable change in the genetic material. In simpler word it can be defined as any change occurring within the organism which is not due to hybridization induced recombination and segregation. Extensive research and findings have been made in the field of mutation breeding especially for vegetable crops for improvement and evolving newer and better varieties which will add up to the current germplasm

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of crops. In a broader way mutation can be divided into two parts, first one is the natural mutation and induced mutation. Induced mutations are those type of mutation that are result of mutagen. Mutagen are the agents that cause the mutation in plant. Plant breeder utilize this type of effect of mutagen on the plant and producing mutants of the crop and the central core idea is to use these mutagens in a such a beneficial way of creating useful variation among the existing plant population. Further talking about mutagens mostly physical and ionizing mutagens have been used since a long time. The use of physical mutagen began with the discovery of X-ray which dates back to 1895 when W.C. Röntgen discovered X-rays. Along with the physical mutagens, EMS (Ethyl methanesulfonate) is also a prominent for inducing mutations chemically (Sega, 1984). Therefore, in most of the cases the physical mutagens along with the chemical mutagens are considered for mutating a population because of their ease as well as higher promising result.

Past achievements of Mutagenesis:

As we discussed before the basic concept of developing mutant variety is to increase the existing characters of current varieties. This improvement can be any of the character like plant height, increased yield, high seed set or any character which plays important role for increasing the economic angle related with the crop. According to the database of FAO/IAEA about 2522 varieties were officially released from year 1966 to 2000, out of which highest were from China (26.8 %), while India and Russia occupied second and third place with 11.5% and 9.3% respectively (Maluszynski, 2000). For vegetables Macro mutation were recorded in different vegetables like dwarfness (French bean, pea, summer squash, muskmelon etc.), Leaf mutants (Pea), Male sterile mutants (tomato, muskmelon etc.) disease resistant mutants (tomato, eggplant, potato etc.) and high nutritional quality mutants (sweet potato, hot peppers *etc*.). But still the vegetable science lacks in the field of mutation breeding as compared to cereals, flower and legumes which share the 47.9 %, 20.1 % and 14.3 % share of the mutant variety over the world respectively. On the other hand, vegetables on share about 2.82% (Agrawal and Kumar, 2021).

Table 1: Significant achievements of Vegetable crops in India through Mutation Breeding

Crop	Variety (Year)	Description
Okra	Anjitha (2006)	Irradiating with 300 Gy gamma rays to seeds of F1 interspecific hybrids of A. esculentus var. Kiran X A. manihot, followed by applying selection pressure for higher yield, fruit quality and YVM resistance upto F6M6 and further evaluation trials resulted in development of Anjitha, a high yielding variety having the fruit characters and quality of the cultivated parent A. esculentus var. Kiran combined with the YVM resistantance of wild parent A. manihot
Cowpea	Co-5(1985)	It was developed by irradiation of seeds with gamma rays (300 Gy). Main improved attributes of mutant variety are

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		more nutritive forage cowpea, high yield (16%), comparable for intercropping with foder cereals.
	COCP 702 (2002)	It was developed by irradiation of seeds with gamma rays (200 Gy). Main improved attributes of mutant variety are high yield and good quality.
	Cowpea 88(1990)	It was developed by irradiation of F1 generation from cross Cowpea-74 X virus resistant strain H-2. Main improved attributes of mutant variety are high grain yield, high green fodder yield, resistance to yellow mosaic virus.
Tomato	Pusa Lal Meeruti (1972)	It was developed by irradiation of dry seeds with gamma rays (300 Gy). Main improved attributes of mutant variety are uniform fruit ripening, high yield and improved fruit color.
	S.12 (1969)	It was developed by irradiation of seeds with gamma rays. Main improved attributes of mutant variety are dwarfness and high yield (30%)
	CO-3(1980)	It was developed by chemical treatment by water solution of 0.1% EMS. Main improved attributes of mutant variety are compact growth, adaptability, fruit shape (round and smooth, high vitamin C content.
	PKM – 1 (1980)	It was developed by irradiation with gamma rays (250 Gy). Main improved attributes of mutant variety are high yield, determinate plant type and good transportability.
Chilli	MDU -1 (1976)	It was developed by irradiation of seeds with gamma rays. Main improved attributes of mutant variety are compact growth, high yield and capsine content.
Eggplant	PKM – 1 (1985)	It was developed by irradiation with gamma rays. Main improved attributes of mutant variety are high yield (34 t/ha), tolerance to drought, suitable for transport and storage to room temperature.
Luffa	PKM – 1 (1984)	It was created by irradiation with gamma rays. Main improved attributes of mutant variety are high yield (28 t/ha), tolerant to pumpkin beetles, fruit fly and leaf spot diseases.

Source: FAO/IAEA database of varieties

Mutagens:

Mutagens are substances that cause DNA alterations. Mutagens are divided into two categories: physical and chemical mutagens, depending on their type. Some scientist they induce gene mutations at rates higher than the spontaneous baseline, which results in the production of novel traits and an increase in the genetic diversity of plants (Lagoda, 2007). The most often used physical and chemical mutagens in crop improvement programs are gamma radiation and ethylene methane sulfonate (EMS) (Kodym and Afza, 2003).

Physical mutagens:

Ionizing radiation damages DNA's double helix structure. Radiation such as X-rays, gamma rays, and neutrons are frequently used. Ionizing gamma rays are the most often employed physical mutagens (Kodym and Afza, 2003). According to some researchers, these

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electromagnetic radiations behave physically and affect organisms similarly to X-rays. Ionizing radiation becomes the most preferred option because of its high penetration, high mutagenesis frequency, convenience of use, and lack of disposal issues. The cellular repair mechanism joins the damaged DNA fragments once they have occurred. The organism's genome undergoes permanent alterations because of increased exposure to ionizing radiation, beyond the capacity of these DNA repair processes to withstand low radiation rates. It causes nucleotide deletions that alter the DNA sequence and cause reading-frame shifts, defective transcripts, and inactive protein products (Jadav *et al*., 2012).

Chemical Mutagen:

A variety of chemical mutations that can permanently alter DNA bases have been found in the quest to prevent ionizing radiation-induced aberrations and their detrimental effects. Ethyl Methane Sulphonate ($CH_3SO_2OC_2H_5$) is one of the chemical mutagens that is used to induce variability. Other chemical mutagens include mustard gas, MMS, and sodium azide (Kodym and Afza, 2003). Chemically generated mutations are more commonly used than radiation treatment due to their simplicity of application. Additionally, they do not need a specific tool, and they can produce point mutations, single base pair alterations, and single nucleotide polymorphisms when the frequency of mutations increases. Chemical mutagenesis treatments are applied to seeds and in vitro produced plant tissues, including vegetative propagules, corms, rhizomes, bulbs, and tubers (Suparna *et al*., 2012).

Mutation breeding methods:

Mutation breeding offers certain advantages over standard hybridization breeding. It has only one parent and avoids the laborious emasculation and pollination. It does not require the source material for the improvement of a specific characteristic. Mutations introduce new variations that were not previously present in existing populations, whereas hybridization works with the variation that already existed in the population (Kantoglu *et al*., 2014). However, mutation breeding is extremely tedious, requiring the thorough and judicial screening of many mutant populations in order to identify acceptable mutants for future selection. Because mutants act randomly on the genome, it is critical to find positive mutants of interest. In hybridization breeding, selection begins with the third year, or F_2 generation, following the crossing of the two homozygous lines. Dominant mutants in mutation breeding can be recognized in the first year or season, or M_1 generation. However, after M_1 selfing, the heterozygous dominant will segregate in the M_1 generation. Therefore, progeny testing is to be used to identify homozygous dominant mutants. In the M_2 generation, homozygous recessive mutants will also be observed (Toker *et al*., 2007).

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Table-2: Differences between hybridization breeding and mutation breeding

Hybridization breeding	Mutation breeding
Creation of variation by crossing two genetically dissimilar parents	Creation of variation by treating with mutagens
Trait specific	Trait non-specific
Variation occurs in F_2 generation	Variation occurs in M_1 generation
Works on the variation within the limit of existing variation	New variation can occur
Specific direction	Directionless
Less laborious	Laborious
Probability of success is more	Probability of success is less, majority are deleterious

Source: Advances in Horticultural Crop Management and Value Addition

Mutation breeding in seed propagated crops:

Because chimeras, a major issue with vegetatively propagated crops, do not develop in seed-propagated vegetable crops belonging to the groups Solanaceae, Fabaceae, Cucrbitaceae, and Malvaceae, mutation breeding in these crops is relatively simple. Obtaining a big quantity of seeds (between 500 and 1000) for mutagenic treatment and transporting the seed material to the gamma chamber are both simple tasks. The main limitation with crop seed propagation is that it produces seeds that are both mutant and non-mutant (Ahloowalia and Maluszynski, 2001). These can be fixed with an effective screening technique and a big population to find the desired mutations. As a result, use seeds to administer mutagenic treatments is thought to be the most common technique in mutant breeding operations.

Mutation in vegetatively propagated species:

Asexually propagated crops, such taro, sweet potatoes, cassava, and others, differ greatly from crops propagated by seed in several aspects, including mutation breeding. Since multicellular actively dividing tissues, such apical or auxiliary buds, are employed in mutagenesis treatments, the various cell types within the tissue typically exhibit distinct types of mutations, making a careful assessment of the mutants' potential for chimeras necessary (Broertjes and Van Harten, 2013).

Table-3: Differences between seed propagated and vegetatively propagated crops for mutation breeding

Seed propagated species	Vegetatively propagated species
Plant material used is seed or pollen unicellular starting material	Plant material is apical or auxiliary buds
Next generation proceeds sexually	Next generation proceeds vegetatively
Further variation occurs due to selfing	Mutation is the only source of variation
The mutagenic generation are indicated as M1, M2. M3 ….	The mutagenic generation are indicated as M1V1, M2V2, M3V3 …
No problem of chimeras	Chimeras are the major problem
Selection starts from M_1 or M_2 generation	Actual selection starts from M1V4

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Comparatively consumes less time	Capacitively consumes more time

Source: Advances in Horticultural Crop Management and Value Addition

Mutation breeding in self-pollinated crop:

Since the mutant traits of self-fertilized crops are recurrent in nature, they are quite simple to understand. The materials must to possess autogamous characteristics and go through at least the M_2 generation before going through phenotypic screening. The plants in this generation will be segregated due to the recurrent mutant characteristic (Yonezawa *et. al*., 1969).

Mutation breeding in cross pollinated crop:

The job is laborious since crops that are mostly cross-fertilized in nature are heterozygous and show a considerable degree of inbreeding depression. It greatly varies the amount of M2 generated during open pollination and selfing. There are very few major mutations of interest that can be identified. Another obstacle that makes the employment of mutant breeding techniques challenging is the presence of self-infertility mechanisms in plant species, such as self-incompatibility (Pathirana, 2011).

CONCLUSION

Crop production must rise to meet the growing demand for food around the world, which calls for the creation of new cultivars with better features. When hybridization is not practical, mutation breeding is useful for producing variations with improved traits including pest resistance, early maturity, and high yield. Its disadvantages include time-consuming screening and dangerous mutations. The efficiency of mutagenesis is being increased by developments in genomics, high-throughput screening, and molecular markers, which makes it an attractive addition to other breeding strategies.

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