Journal of Advances in Science and Technology
Vol. 21, Issue No. 1, March-2024, ISSN 2230-9659

A Study on Mutation Breeding for Crop Improvement

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Abstract- Despite the tremendous changes happening in the world of agriculture, food insecurity is still an issue. To meet the 70% increase in food consumption by 2050 predicted by the global population, it is essential to improve crop varieties in order to make them more resistant to climate change, efficient with inputs, provide more nutrient-dense food, and operate better in different agro-ecosystems without negatively impacting the environment. A total of 3,362 mutant plant kinds have been published from more than 75 different nations as a result of the very popular breeding method known as mutation breeding, sometimes known as induced mutation. Genetic diversity in crops has been enhanced by the application of physical, chemical, and hybrid mutagens. Of these, 82 are indigenous to Africa and 959 are native to Asia, the Pacific, Australia, Europe, Latin America, and North America. Other notable crop types that have resulted from mutation breeding and forced mutation include 1602 cereals, 501 legumes, and 86 oil seed mutant. Raising agricultural productivity and ending global hunger, this method improves quantitative and qualitative characteristics across a wide range of crops. Developments in biotechnology, genetics, and plant breeding have enabled this improvement.

Keywords- Mutation, Crop, improvement, agriculture

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INTRODUCTION

One of the most effective methods of plant breeding, mutation breeding uses artificially introduced genetic differences to create better crop types. Mutation breeding uses physical or chemical substances to intentionally induce mutations, as opposed to conventional breeding approaches that depend on naturally occurring genetic variety. A big benefit in dealing with the always changing problems in agriculture is that this method speeds up the production of new features that may develop via natural processes, which might take a lot longer.

In the early 20th century, scientists started to grasp the significance of mutations in inheritance, which led to the notion of mutant breeding. Induced mutations were first put into practice for crop improvement with Wilhelm Conrad Roentgen's discovery of X-rays and Hermann Joseph Muller's subsequent realisation of their mutagenic effects. There has been a proliferation of mutation breeding methods since then, made possible by the discovery of new mutagenic agents including gamma rays and chemical mutagens like ethyl methanesulfonate (EMS).

Generating a broad range of genetic variation is one of the main benefits of mutant breeding. Plant breeders rely on this variety to improve nutritional quality, stress tolerance, disease resistance, and crop output. For example, barley with better malting quality, wheat varieties with increased drought tolerance, and rice cultivars with higher resistance to diseases like blast and bacterial blight have all been developed via mutation breeding. Not only do these upgrades help farmers out with crop resilience and production, but they also add to food security and sustainability. Mutation breeding also helps enhance crops with low levels of genetic diversity or those grown vegetatively. The absence of inherent genetic diversity and the difficulties of crossing make traditional breeding techniques problematic in these crops. New opportunities for agricultural enhancement have emerged thanks to mutation breeding, which gets around these problems by directly causing genetic alterations.

The first of several stages in mutant breeding is deciding which crops to work on and which characteristics to enhance. Next, plant tissues such as seeds or seedlings are treated with a mutagenic agent. Then, mutants with the required traits are screened and selected. Mutation breeding has become a more focused and successful strategy with the use of advanced techniques like TILLING (Targeting Induced Local Lesions IN Genomes) and high-throughput sequencing, which have further improved the efficiency and accuracy of detecting advantageous mutations. Mutation breeding does have its benefits, but it also has its share of problems. Extensive screening is required to find beneficial mutants since, due to the random nature of mutations, many produced alterations are neutral or harmful. Mutation breeding is not universally adopted and has different effects in different nations due to differences in the regulatory framework for the release and marketing of mutant types.

The most pressing issue of the twenty-first century is ensuring enough food supplies for a growing global population. Forecasts indicate that the global population might reach 9.1 billion in 2050, a 34% increase from the current estimate (FAO, 2009). There has to be 70% more food production to fulfil the need of a rising population, which clearly puts a huge strain on the current environment and agricultural output. Controlling the unexpected ecological and meteorological variations is essential to achieving this improvement in food production (Charles et al., 2014). The Food and Agriculture Organisation of the United Nations (2011) proposed a solution to this problem: the development of low-input crop varieties in the 21st century. These varieties should be more adaptable to different agro-ecosystems and farming methods, have higher yields while using less inputs, and have better nutritional attributes. In addition to these practices, there are a number of policies that could be put in place to ensure that the world has enough food by 2050. These include: regulating the use of groundwater, encouraging efficient water handling systems like Israel's and setting appropriate prices for water; expanding research into more sustainable and environmentally friendly E.g., a sustainable farming system that prioritises long-term yield over short-term gains, a carbon tax system that prioritises cost-effective renewable energy, etc. The very limited genetic base of available crop varieties is a big hurdle when it comes to breeding desirable crop varieties that may increase farm output and lead to food security (Khursheed et al., 2019). One of the biggest challenges in ensuring food security is increasing agricultural productivity. Both Raina et al. (2016) and Laskar et al. (2018) argue that crop improvement programmes should have focused on creating a variety that can withstand changing weather conditions while still yielding high yields. This is because plant breeders face a huge challenge from global climate change, which threatens crop productivity. They need a larger genetic foundation of desired crops and variety between themselves to generate these kinds. To satisfy the demands of the modern era, induced mutagenesis has been used to generate genetic diversity in agro-economic parameters (Mba et al., 2012).

One of the most important factors in improving crops is variation, which comprises morphological, physiological, cytological, and behavioural changes across species. One of the many sources of variation is mutation. A man known as the "father of mutation" is Hugo de Vries. His usage of the word "mutation" to describe heritable phenotypic alterations dates back to 1900. Any alteration to an organism's genetic code is known as a mutation (Ripley, 2013). Two pathways lead to mutations; To begin, there is spontaneous mutation, which happens when an organism does not receive any external mutagen therapy. Second, induced mutations may happen when plants or its components (seed, stem, cuttings, pollen, and ovules) are exposed to mutagens. Mutation breeding refers to the practice of intentionally using produced mutations to enhance crops (Pathirana, 2011). Physical, chemical, or biological factors may create mutations or mutagenesis, which are rapid heritable changes in an organism's genome that are not caused by genetic recombination or segregation (Roychowdhury & Tah, 2013). A reasonable instrument for creating genetic variety in crops, mutation breeding is one of numerous breeding approaches available.

LITERATURE OF REVIEW

Baadu et al. (2023) Lewis Stadler began working on ways to permanently alter the genetic composition of irradiated plants in the 1920s. Efforts to increase and enhance agricultural output and quality have led to a rise in research on breeding mutations since then. Early on, Stadler used x-rays on maize and barley; subsequently, he expanded his methods to include gamma-rays, thermal imaging, and fast neutrons. Radiation is now known to be a novel and efficient way to increase the genetic diversity of many organisms, including rice. Researchers in Southeast Asia have looked at how physical mutagens affect rice yield and quality in a number of systematic studies. What is missing from the current research, however, is data about the radiation kind, planting materials for the rice, physical mutagen dose, and variations in mutant traits. Consequently, the purpose of this paper is to survey the research on physical mutagens used in Southeast Asian rice crops. After searching the databases of Scopus, Science Direct, Emerald Insight, Multidisciplinary Digital Publishing, and MDPI for articles published between 2016 and 2020, a total of 28 main investigations were located using the PRISMA Statement as a guide. The findings reveal that a staggering 96% of the papers discussed seeds as a planting material, with an additional 80% centering on gamma-rays as a physical mutagen. For the best results in terms of plant growth, abiotic stress, biochemical characteristics, and rice's nutritional and industrial quality, gamma-ray dosages of 100 to 250 Gy were recommended.

Pandit et al. (2021) our worries about food insecurity persist even if the world's agriculture sector is undergoing a period of fast transformation. There will be a 70% rise in food consumption by 2050 to keep up with the exponential growth in population. We can only get out of this jam if we upgrade our current crop varieties to be more resilient to climate change, efficient with our inputs, produce more food with better nutritional value, and work better in a variety of agro-ecosystems without harming the environment. The creation of genetic variety among crop types is greatly aided by mutation breeding, also known as induced mutation, among other breeding techniques. The practice of mutation breeding has grown in popularity over the last half-century, leading to the publication of 3,362 mutant plant types. These variations represent 240 distinct plant species and come from over 75 different nations. Many breeders have experimented with physical, chemical, and hybrid mutagens to increase genetic diversity in crops. Physical mutagens are responsible for the development of 2,635 variants, chemical mutagens for 398 types, and a mix of the two for 37 kinds. Through the process of mutation breeding or induced mutation, 86 major oil seed mutant crop types have been created, along with 501 major legumes and major cereals. Multitudes of cereal, grain legume, oil seed, vegetable, fruit, medicinal, decorative, and fodder crops have benefited from mutation breeding, which enhances both quantitative and qualitative traits in these plants. Mutation breeding helps boost agricultural output, which in turn helps end world hunger and improve people's nutritional status as a result of developments in plant breeding, genetics, and biotechnological techniques.

Ansari et al. (2021) there is a wide variety of commercially significant plants that belong to the oilseed crop category. Among all agricultural commodities, vegetable oil has a very high trading share of 42%. Root vegetables pair well with oilseeds because of the high levels of protein and fat they provide. Their by-products are used for industrial and fuelwood applications, and they have several uses, including whole seed, vegetable oil, cake oil, and other derivatives. Soybean, rapeseed, cottonseed, and groundnut are some of the most widely used oilseed crops in the world. Less common oilseed crops, such castor, linseed, and fenugreek, are also used in many other products, including biodiesel, pet food, and pharmaceuticals. The US, Brazil, Argentina, China, and India are the leading oilseed producing nations. Worldwide, the most promising strategy is increasing oil production while simultaneously improving oil quality via the use of mutant breeding techniques. Various crops' nutritional properties have unquestionably improved as a result of the use of chemical, physical, and combination mutagens. In nations whose food is financed mostly by oil and other main commodity exports, prices have increased significantly.

Chaudhary et al. (2019) A powerful method for improving crops, induced mutagenesis may generate genetic variety and reveal essential regulatory genes. Physical, chemical, and insertional mutagen treatments used to be time-consuming and costly, but next-generation sequencing (NGS) methods have made them easy and simple. One powerful tool for both forward and reverse genetics is the combination of induced mutagenesis with whole-genome sequencing. In order to design precise mutations in plants, scientists have turned to genome editing tools including CRISPR/Cas9 endonuclease, TALENS, and ZFNs. Genome editing has been revolutionised by CRISPR/Cas9 because of its simplicity and resilience, This makes it a perfect choice for enhancing resilience to both natural and artificial pressures. The search for novel genes with the potential to improve crops is the subject of this Special Issue of Plants, which delves into the current scientific obsession with mutagenesis.

Zakir (2018) the projected challenges in food production are caused by fluctuating climate conditions, diminishing water resources, and a lack of arable land. Due to urbanisation, salinization, biotic stress, drought, and desertification, there is less arable land, which only makes things worse. There are a variety of methods for improving agricultural yields by tapping into the genetic differences already present in crop plants. One way to expedite crop development is to include desirable features from nonadapted landraces or crop natural resources. One of the many ways that induced mutagenesis has helped crop improvement programmes is by creating mutant kinds of agricultural plants with improved and desirable genetic alterations in agronomically important traits. Such genetic alterations may be experimentally generated by physical and chemical mutagens or occur naturally at very low rates. You did a good job reviewing the literature on topics such as the processes of mutation induction, the role of mutation breeding in crop development, the approach to mutation breeding that yields mutants, and the economic effects of new mutant varieties.

MUTATION AND ITS TYPES

The term "mutation," first used by De Vries in 1901 to characterise a quick change in the genotype of an organism, is believed to have originated with him. This trait, first observed in the common evening primrose (Oenothera lamarkiana), is now used to identify species that exhibit similar alterations. Genetic variations are the building blocks of evolution, and mutation is the mother of all genetic alterations in addition to being a great tool for enhancing the economically beneficial features of plants. These genetic alterations may be introduced experimentally using physical and chemical mutagens or, very rarely, they can happen naturally.

- **Naturally Occurring Changes**

During adaptations and evolutionary processes, agricultural plants naturally undergo very low rates of spontaneous mutations, with a rate of 10-5-10-8. Variations in a crop's genetic architecture can't be introduced at this frequency to enhance desired qualities (Zhong- hua et al., 2014). Instances of heritable, irreversible change—specifically, spontaneous mutation—occurring during domestication have resulted in mutant varieties such as wheat, peas, and barley. These plants' reduced seed dormancy periods and elimination of pod or head breaking were both brought about by spontaneous mutations. Almonds, lima beans, watermelons, potatoes, eggplants, cabbage, and a number of nut varieties also include spontaneous mutations (Mba, 2013). Thanks to the introduction of naturally occurring mutations in wheat types, which increased production and made them more resistant to lodging, the green revolution was able to take place, providing food for millions of people all over the globe.

- **Mutation induction**

Novel alleles of structural or regulatory genes have been selected for by humans, leading to several traits that are significant in plant domestication and improvement (Olsen and Wendel, 2013). Physical and chemical mutagenesis have been used by plant breeders to create genetic variety since the 1920s (Stadler, 1928). From a mechanistic standpoint, plant phenotypic is unaffected by mutations in DNA that originate in nature or are intentionally introduced by humans. In both instances, changes to cis-regulation, DNA sequence deletion or insertion, or nucleotide substitution might affect gene function. Certain characteristics in crop species have been acquired by mutations in the same genes, either through natural selection or through intentional selection. Ashikari et al. (2002) noted that the Green Revolution was made possible, in part, by semi-dwarf rice types that evolved apart from regular rice due to mutations in the gibberellin 20-oxidase gene. Breeding hexaploid wheat with a mix of naturally occurring and artificially induced mutations in waxy homologs has allowed researchers to alter the starch quality of the crop. The majority of the variants documented in the FAO/IAEA Mutant variations Database (77%) may be attributed to physical mutagens, which were the first methods for inducing mutations in plants. Common types of ionising radiation used for physical mutagenesis include gamma and X-ray ionisation, as well as fast neutron bombardment. While deletions are more prevalent than unique single nucleotide polymorphisms (SNPs) in Arabidopsis thaliana, gamma radiation increases the frequency of point mutations and short deletions.

i. Chemical Mutagenesis

It wasn't until 1939 that Thom and Steinberger found that nitrous acid affected mutations in Aspergillus. A lot of people had attempted to use chemicals to cause mutations before this, but they hadn't gotten any convincing results. Afterwards, scientists presented convincing evidence that the best mutations are those that alter preexisting genes. Using a combination of markers allowed for more accurate evaluations of people with mosaic or fractional patterns. The specificity and effectiveness of chemical mutagens in causing real gene modifications were determined by analysing their reactivity with different DNA bases. Due of its ability to generate SNP mutations with little to no specialised equipment, chemical mutagenesis has become more popular. Methyl methane sulfonate (EMS) is the most often employed chemical mutagen, but sodium azide, diethyl sulphate, diepoxybutane, and methylnitrosourea are also effective options. The specific way in which a chemical causes mutations might affect how severe those mutations are. As an example, EMS preferentially alkylates guanine bases, which leads to GC to AT conversions. By injecting flowers with ethyl methane sulfonate (EMS), scientists were able to conduct chemical mutagenesis and produce peanut mutants with higher yields. By injecting 0.3% EMS into the flowers of Huayu 16 and then selecting for it, a high-yielding peanut cultivar called Huayu 40 was established based on the results of numerous researchers. An improved cultivar, Huayu 40, develops straight stems and successive branches. Wild Huayu 16 grows more slowly and has lighter green leaves, whereas Huayu 40 grows quicker and has deeper green foliage. Furthermore, compared to Huayu 16, Huayu 40 exhibited significantly higher amounts of chlorophyll a, b, and leaf water content. The use of EMS mutagenesis allowed for the production of several groundnut mutants that could differentiate within their own species. Seed yield and composition have been enhanced in mung beans and chickpeas by means of induced mutation. "Golden" produced better results in a number of ways, including larger seeds and more pods per plant. Not even the peanut variety called "Georgia Browne" is immune to the presence of big seeded mutant lines. Groundnuts have been genetically engineered to produce a rainbow of seed coat colours in the past. In higher plants, the use of chemical mutagens has been shown to enhance genetic diversity. This improves the chances of successful breeding programmes for sexually or vegetatively generated plants.

ii. Physical Mutagenesis

Particle and electromagnetic radiation, including beta and alpha particles, gamma rays, X-rays, and ultraviolet light, may produce physical mutagens. An effective physical mutagen's ability to cause mutations depends on both the genotype and the properties of the physical agent. The small-seeded, high-yielding, disease-resistant variety Georgia Brown was gamma irradiated to identify several large-seeded lines that demonstrated substantial diversity in disease incidence, pod yield, total sound matured kernels, pod weight, seed weight, and seed size dispersion. Various forms of early-maturing may be attributed to mutagenesis and crosses involving mutants. Groundnuts were the first subjects of X-ray studies on induced mutations. Over the last fifty years, physical mutagen testing on groundnuts has been quite rare. Researchers may have reached vastly different conclusions on the ideal concentrations of substances to avoid mutagenesis effects due to differences in genetic predisposition and physiological states. Effective doses of X- and gamma radiation for groundnuts vary between 100 and 450 Gy. Applying several mutagens to groundnuts has shown their potential to produce mutations. In reality, gamma rays have been the most common mutagen; in fact, mutants that were caused by gamma irradiation account for more than 80% of all mutant types. There are a total of 71 mutant varieties that are linked to the Arachis hypogaea species, according to the FAO/IAEA Mutant Variety Database. The following radiations are examples of physical mutagens: alpha rays, beta rays, fast neutrons, thermal neutrons, X-rays, gamma rays, UV radiation, and ten X-ray variations, forty-one gamma varieties, twelve beta varieties, and two laser varieties formed from these.

iii. Mutation Breeding's Impact on Crop Improvement and a Few Standout Mutant Varieties

- **Rice Genetic Improvement**

As an example of the practical effect of induced rice mutants, consider the enhanced rice types that have been developed via mutation breeding. In 1957, two Chinese rice varieties—KT 20-74 and SH 30-21—were introduced to the market. The first variety, Yenhsing-1, was created via a cross-breeding process including a mutant (Rutger, 1992). Then, not long after, the lodging-resistant semi-dwarf mutant Reimei was introduced to the Japanese market, greatly increasing yield. Two semi-dwarf rice varieties that have recently transformed their respective rice production systems are Basmati 370 (a long grain with a short stalk) and Calrose 76 (a short stalk with a stiff stalk). Awan (1991) reported that induced mutation in Basmati 370 produced a new variety of Basmati in Pakistan called Kashmir Basmati. This variety develops earlier, can withstand colder temperatures, and still maintains the parent variety's fragrance and cooking quality. The PNR series in India produced a number of high-yielding rice mutants, some of which matured prematurely and were somewhat low in stature (Chakrabarti, 1995). Of these, two kinds of aromatic mutation-derived early-ripening rice, "PNR- 381" and "PNR- 102," are widely grown in the states of Haryana and Uttar Pradesh. The "Zhefu 802" mutant rice variety was grown on about 10.6 million hectares in China over the course of a decade. Gamma ray irradiations hastened the 1977 introduction of a fragrant indica rice variety called "RD6" in Thailand. It was cultivated widely over 2.4 million hectares in 1994 and 1995. The 0.2 million hectares (ha) that were cultivated with the 1978-released mutant "RD15" accounted for 3.2% of the total rice-growing area (Anonymous, 1995). Nine different mutant types of rice have been produced in Australia: "Amaroo" (1987), "Bogan" (1987), "Echua" (1989), "Harra" (1991), "Illabong" (1993), "Jarrah" (1993), "Langi" (1994), "Millin" (1995), and "Namaga" (1997). An important step in developing methods for creating hybrid rice types was the introduction of the thermosensitive genic male-sterile (TGMS) mutant into the Japonica rice mutant PL-12, which is regulated by a single recessive gene (Maruyama et al., 1991).

- **Establishing Wheat Crop Drought and Salinity Tolerance**

The semi-dwarf, non-lodging mutant variety known as "Sharbati Sonora" has been an invaluable asset to India's wheat crop. The Indian Agriculture Research Institute in New Delhi, India, created the "Sharbati Sonora" cultivar by gamma irradiating red-grained Mexican Sonara 60. A mutant Stadler with improved lodging resistance, early maturity, resistance to leaf rot and loose smut, and large yields was created in Missouri, USA (Anonymous, 1977). Because of the cold-tolerant mutant types, the area where durum wheat was cultivated in Italy was greatly increased.

- **Improving Barley Crop Tolerance to Lodging**

With the emergence of "Diamant" and "Golden Promise," a gamma-ray induced semi-dwarf mutant, the brewing industry in Europe was completely transformed by the effective application of mutation breeding in barley breeding. In Europe, several barley varieties were created by crosses of "Diamant." Countless popular barely types introduced to the European market may trace their ancestry back to these high-yielding mutants. Centenario, which was introduced in 2006 and has a high protein content, early maturity, resistance to yellow rust, and a large yield, greatly aids the country's food security (Gomezpando et al., 2009). According to an anonymous source from 1977, the "Luther" gamma-ray generated mutant showed a 20% increase in yield, stronger tillering resistance, and better lodging resistance. On the other hand, the "Pennrad" mutant exhibited winter hardiness, improved lodging resistance, and early ripening.

- **Breeding Peanut Seedlings with Accelerated Maturation Quite a few peanut**

In China, the "Yueyou" series introduced several mutants that were induced with gamma radiation; these included Yueyou No. 5, Yueyou No. 22, Yueyou No. 33, Yueyou 551, and Yueyou 187. Among these, Changua No. 4, Lainog, Yueyou 551-38, and Yueyou 551 featured early maturity and improved yield. The Bhabha Atomic Research Centre in Bombay created a mutant peanut species called TG 26. It can withstand severe illnesses in the field, matures early, sets pods compactly, bears more pods, has a higher harvest index, and is semi-dwarf in stature (Kale et al., 2007).

- **Varieties of Chickpeas That Are Highly Productive and Resistant to Wilt**

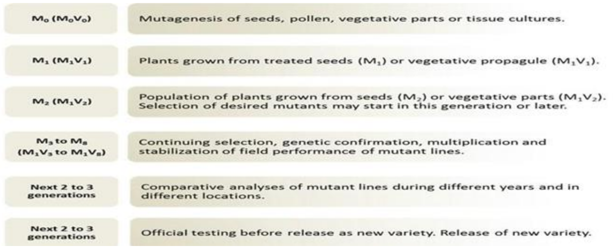
A number of chickpea mutants with increased yields and resistance to wilt disease were developed at the I.A.R.I. in New Delhi. Ajay, Pusa-413, Girnar, and Pusa-547 are all examples of such mutants. The use of induced micro-mutants in a global bean crop is the basis for these mutants. The mutant variety Pusa-547 was released in 2006 and is described by many sources as having a thin testa, attractive bold seeds, enhanced cooking quality, and high production performance when planted late in the North-Western part of India (Khakwal et al., 2005; Kozgar & Kans, 2009).

iv. Techniques for Mutation Breeding in Order to Generate Mutants

A methodical procedure is necessary for the breeding of any mutant. Step one in mutant breeding is to drastically decrease the number of possible variations in the first (M1) plant generation's mutagenized seeds or propagules. This will allow for more thorough study and assessment. Your chances of success with mutation breeding methods are much higher if you know how many mutants you want to produce in the first generation. Executing a plethora of mutation measurements becomes much simpler when a target population is already known. Breeders must maintain vigilant vigilance over population growth because to this. How the target gene is passed down across generations dictates the size of the population. The number of M1 generations may be decreased by using mutagens that induce mutations at a high frequency.

The M1 mutation is seen in plants with a heterozygous genetic makeup. Any mutations brought about by a treatment can only impact a single allele. It is possible for a mutation to occur concurrently, however, as the mutation probabilities for both alleles are combined together. Reciprocal mutant expression in M1 cannot be detected at this time either; only dominant mutations can be recognised. If plant breeders are serious about ending segregation in the future, they may try screening mutations. Due to hybridization caused by pollination of the M1 population, mutations would be hard to tell apart from the offspring.

Moving on to the M2 generation, we will go over the three primary methods of screening and selection. Methods such as visual/phenotypic, physical/mechanical, and others fall under this category. Sorting seeds by size, density, shape, weight, and other characteristics may be as simple as using the correct screening equipment in conjunction with physical or mechanical selection. When looking for abnormal characteristics, visual screening is your best bet. Adaptation to diverse climates, growth rates, soil types, diseases, colour changes, early maturity, non-shattering, and many other traits may be selected for in plants via visual and phenotypic selection. The "others" group of screening methods includes physiological, biochemical, chemical, and physiochemical elements that might be used to choose for certain mutant variations.When a mutant line has promising traits, the next step is to multiply the seeds for further field testing. Various sorts of mutant lines will be compared to the mother cultivar in this section. Extensive study in diverse habitats with differing water availability, plant densities, sowing dates, and other factors should be conducted on the potential mutant before it is introduced as a commercial variety. Several characteristics, including as structure, yield components, and growth habit, should be investigated in this study (Roychowdhury and Tah, 2013).



M_0 (M_0V_0)	Mutagenesis of seeds, pollen, vegetative parts or tissue cultures.
M_1 (M_1V_1)	Plants grown from treated seeds (M_1) or vegetative propagule (M_1V_1).
M_2 (M_1V_2)	Population of plants grown from seeds (M_2) or vegetative parts (M_1V_2). Selection of desired mutants may start in this generation or later.
M_3 to M_8 (M_1V_3 to M_1V_8)	Continuing selection, genetic confirmation, multiplication and stabilization of field performance of mutant lines.
Next 2 to 3 generations	Comparative analyses of mutant lines during different years and in different locations.
Next 2 to 3 generations	Official testing before release as new variety. Release of new variety.

Figure 1: Traditional mutatation breeeding scheme

Nomenclature for generations starts with M0 for pollen or seed mutagenesis, with M0V0 for vegetative organs, and with M for meiotic generation. Prior to mutagenesis, all materials are assigned a "0" and a "1" after the process is finished. Due of the high level of genotypic diversity that arises from mutagenizing multicellular material, the first generation of plants cannot be used for evaluation (chimeric). As far as we know, the M2 is the first non-chimaera generation of seed-mutated and seed-propagated material. Mutant allele inheritance stability and genetic homogeneity in vegetatively produced material may need many cycles. The initial non-chimeric generation may be used to start screening and selecting. To make sure the features can be passed down across generations, it is common practice to select for and assess mutant phenotypes. Upon completion of this step, the materials may be prepared for varietal release testing. Another option is to employ materials in breeding projects as parents. The Mutant Variety Database, which can be searched, contains information on officially published mutant crop varieties that have been submitted to the Joint FAO/IAEA Programme (MVD 2016).

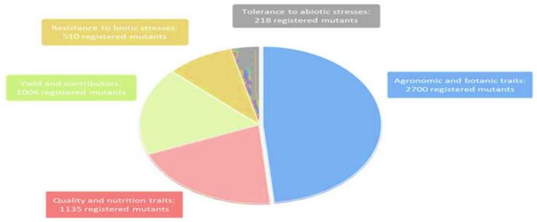


Figure 2: Mutants registered in the MVD

There is a total of 5569 descriptions of enhanced characteristics for 3222 types. The five main groups into which they are grouped are as follows: "agronomic and botanic traits" (48%), "quality and nutrition traits" (20%), "yield and contributors" (18%), "resistance to biotic stresses" (9%), and "tolerance to abiotic stresses" (4%). Maturity, blooming period, and plant structure are all examples of agronomic and botanical features.

v. The Proposed Economic Effects of a Novel Mutant Variety

New crop varieties' monetary worth can be determined by various factors such as higher yield per acre, improved quality, reduced pesticide and fungicide use, drought tolerance, early crop rotation, improved processing quality and value of products, consumer preference for certain qualities, higher nutritional value, longer oil shelf life, and less pesticide use. These benefits can also lead to more land use for crop rotation and increased value in various products like oil, starch, malt, beer, and whisky.

Crop	Country	Mutant Variety	Basis of Value Assessment	Value/Area
Cereals				
Rice	Thailand	RD6 and RD15	Total crop value at farm gate for the period 1989–98	US$ 16.9 billion
China	Zhefu 802	Cumulative planted area between 1986–1994	10.6 million ha	
Japan	18 varieties	Total crop value in 1997	US$ 937 million	
India	PNR-102 and PNR-381	Annual crop value	US$ 1,748 million	
Australia	Amaroo	Current annual planted area	60–70% of rice growing area in Australia	
Costa Rica	Camago 8	Current annual planted area	30% of rice growing area in Costa Rica	
Vietnam	TNDB100 and THDB	Total planted area in 1999	220,000 ha	
Myanmar	Shwewartun	Total planted area in 1993	800,000 ha	
Bread wheat	Pakistan	Jauhar 78, Soghat 90, Kiran 95	Additional income to farmers during 1991–99	US$ 87.1 million
Durum wheat	Italy	Creso	Additional income to farmers during 1983–93	US$ 1.8 billion
Barley	UK-Scotland	Golden Promise	Crop value (1977–2001)	US$ 417 million
Numerous European countries	Diamant and derived varieties	Area planted in 1972	2.86 million ha	
Legumes				
Chickpea	Pakistan	CM 88; CM 98	Additional annual income to the growers	US$ 9.6 million
Blackgram (urdbean)	India, Maharashtra State	TAU-1	Value of increased production in season 1998–1999	US$ 64.7 million
Oil and Industrial Crops				
Cotton	Pakistan	NIAB-78	Total value of crop from 1983–1993	US$ 3 billion
NIAB-78	Additional income to growers from 1983 onwards	US$ 486 million		
Sunflower	USA	NuSun	Grown area in 1994	50,000 ha
Fruit Trees				
Japanese pear	Japan	Gold Nijisseiki	Additional annual income to growers	US$ 30 million
Grapefruit	USA, Texas	Rio Star	Grown area (year 2000)	7,300 ha (75% of total area)

CONCLUSION

The future of global agriculture is in jeopardy due to three factors: rising global populations, shrinking arable land, and shifting weather patterns. To quickly and efficiently resolve these challenges and produce new germplasm, plant mutant breeding is an important component. One of the ways that plants may be improved for human use is via mutation breeding. The enhancement of agricultural plants was achieved by the employment of several mutant breeding techniques. Only particle radiation (e.g., fast and thermal neutrons, ß and alfa particles) and electromagnetic radiation (e.g., gamma rays, X-rays, UV light) have been used in physical mutagenesis so far. Among these physical mutagenesis methods, radiation was the one most often used to enhance agricultural yields. For the purpose of agricultural plant improvement, chemical mutagens such as ethyl methane sulfonate (EMS), sodium azide (NaN3) seed treatment, and diethyl sulphate (DES) were used. Variegated genetic material is essential for fruitful plant breeding programmes, whether the plants are reproduced vegetatively or sexually, and chemical mutagens play a significant role in this process. An major part of induced mutagenesis's contribution has been the creation of mutants in many agricultural plants. There has been a considerable improvement in people's standard of living, as well as food and nutritional security, as a result of the worldwide cultivation of mutant cultivars that possess desirable traits including high yield and resilience to both biotic and abiotic challenges. Despite the availability of mutant resources, there are still challenges to meeting the food needs of an expanding population. Plants that have had their mutant resources established may exhibit traits such as increased yields, tolerance to biotic and abiotic stressors, enhanced rooting systems, greater absorption of certain metals, and altered oil, starch, and protein content, which might enhance industrial processing.

REFERENCES

1. [Ahloowalia B.S, Maluszynski M., Nichterlein K.(2004). Global impact of mutation-derived varieties, Kluwer Academic Publishers. Printed in the Netherlands. Review Euphytica 135: 187–204

2. Altenburg, E. and L. S. Browning (1961). The relatively high frequency of whole-body mutations compared with fractional induced by X-rays in Drosophila sperm. Genetics 16: 203-212.

3. Anonymous (1995). Bureau of Economic and Agricultural Statistics, Bangkok

4. Anonymous (1977). Manual on Mutation Breeding (Second Edition), Technical Reports Series, No. 119. Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria.;288-290.

5. Ashikari M, Sasaki A, Eunuch-Tanaka M (2002). Loss-of-function of a rice gibberellin biosynthetic gene, GA20 oxidase (GA20ox-2), led to the rice „green revolution‟. Breed Sci 52:143–15

6. Awan MA (1991). Use of induced mutations for crop improvement in Pakistan. Plant Mutation Breeding for Crop Improvement 1:67-72.

7. Belfield EJ, Gann X, Methane A(2012). Genome-wide analysis of mutations in mutant lineages selected following fast-neutron irradiation mutagenesis of Arabidopsis thaliana . Genome Res 22:1306–1315

8. Branch WD (2002). Variability among advanced gamma irradiation induced large-seeded mutant breeding lines in the „Georgia Brown‟ peanut cultivar. Plant Breeding, 121: 275.

9. Chakrabarti SN(1995). Mutation breeding in India with particular reference to PNR rice varieties. Journal of Nuclear Agriculture and Biology. 24:73-82.

10. Devlin Kuyek (2002). Genetically Modified Crops in Africa: Implications for Small Farmers

11. De Varies H (1901). Die mutations theories, Leipzig. (State V)

12. Dong C, Dalton-Morgan J, Vincent K, Sharp P (2009). A modified TILLING method for wheat breeding. Plant Genome 2:39–47

13. Gómez-Pando L, Eguiluz A, Jimenez J, Falconí J, Aguilar EH (2009). Barley (Hordeun vulgare) and kiwicha (Amaranthus caudatus) improvement by mutation induction in Peru. Induced Plant Mutations in the Genomics Era, Food and Agriculture Organization of the United Nations, Rome;371-4.

14. Gowda MC, Nadaf HL, Sheshagiri R (1996). The role of mutations in intraspecific differentiation of groundnut (Arachis hypogaea L.). Euphytica. 90: 105-113.

15. Greene EA, Codomo CA, Taylor NE (2003). Spectrum of chemically induced mutations from a large-scale reverse-genetic screen in Arabidopsis. Genetics 164:731–740

16. Hancock CN, Zhang F, Floyd K(2011). The rice miniature inverted repeat transposable element mPing is an effective insertional mutagen in soybean. Plant Physiol 157:552–562

17. Harloff HJ, Lemcke S, Mittasch J(2012). A mutation screening platform for rapeseed (Brassica napus L.) and the detection of sinapine biosynthesis mutants. Theor Appl Genet 124:957–969

18. Jain SM (2002) . A review of induction of mutations in fruits of tropical and subtropical regions. Acta Horticult 575:295–302

19. Jain SM (2010a). In vitro mutagenesis in banana (Musa spp.) improvement. Acta Horticult 879:605–614

20. Jankowicz-Cieslak J ,Thomas HT, Jochen K , Bradley JT (Editors ,2017). Biotechnologies for Plant Mutation Breeding, Protocols; Library of Congress Control Number; © International Atomic Energy Agency ISBN 978-3-319-45019-3

21. Kale MD, Mouli C, Murty GS, Rao MV (2007). Development of a new groundnut variety 'TG-26' by using induced mutants in cross breeding

22. Kharkwal MC, Nagar JP, Kala YK. BGM (2005). A high yielding chickpea (Cicer arietinum L.) mutant variety for late sown condition in north western plain zone of India. The Indian Journal of Genetics and Plant Breeding ; 65(3):229-30.

23. Khattak, G. S. S., M. Ashraf, R. Zamir, I. Saeed (2007). High yielding desi chickpea (Cicer arietinum L.) variety “NIFA-2005”. Pak. J. Bot., 39 (1): 93-102.

24. Kleinhofs A , Owais W, Nilan R (1978). Azide; Mutation Research 55, 165–195.

25. Kozgar MI, Khan S(2009). Genetic improvement of chickpea through induced mutation. Journal of Phytology;1(6).

26. Maluszynski M (2001). Officially released mutant varieties–the FAO/IAEA database. Plant Cell Tiss Org Cult 65:175–177

27. Maruyama K, Araki H, Kato H (1991). Thermosensitive genetic male sterility induced by irradiation. Rice genetics II; 227-35.

28. Mashenkov A (1986). Induced mutation process as a source of new Mutants; Maize Genetics Cooperation newsletter 60, 70-71.

29. Mba C (2013). Induced mutations unleash the potentials of plant genetic resources for food and agriculture. Agronomie 3:200–231

30. Mba C, Afza R, Jain SM (2007). Induced mutations for enhancing salinity tolerance in rice. In: Jenks MA, Hasegawa PM, Jain SM (eds) Advances in molecular breeding towards drought and salt tolerant crops. Springer, Berlin, pp 413–454

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