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The contribution of mutation induction to crop improvement: Addressing climate change and ensuring food security

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La contribución de la inducción de mutaciones a la mejora de cultivos: abordando el cambio climático y garantizando la seguridad alimentaria

Resumen

Para la mejora genética de especies de importancia agrícola, es esencial contar con una amplia base genética, garantizando una variabilidad suficiente para aumentar las oportunidades de selección de rasgos específicos de interés en el campo. Además, el uso de técnicas complementarias a los sistemas de mejoramiento convencional es crucial para explorar eficazmente la variabilidad genética disponible. Actualmente, existen diversas técnicas, como el cultivo in vitro, la transformación genética, la edición génica, la selección asistida por marcadores y la inducción de mutaciones, entre otras. Esta revisión tiene como objetivo sintetizar el desarrollo histórico, las aplicaciones actuales y el potencial futuro de la inducción de mutaciones en la mejora de cultivos, con énfasis en su papel en la adaptación al cambio climático y la seguridad alimentaria. Las técnicas de inducción de mutaciones han desempeñado un papel clave en la respuesta a los desafíos relacionados con la seguridad alimentaria al promover el desarrollo de nuevas variedades para el sector agrícola en diversos países. A través del análisis de la base de datos de variedades mutantes de la FAO/OIEA, fue posible identificar cómo la inducción de mutaciones ha contribuido al desarrollo de cultivares adaptados a las necesidades específicas de seguridad alimentaria y clima. El programa FAO/OIEA (https://nucleus.iaea.org), que promueve el uso de técnicas nucleares en la agricultura, ha dado lugar a la liberación de más de 3404 variedades mutantes en 233 especies cultivadas en 75 países. En varios países, como se indica en la MVD, el uso de germoplasma mutante en los programas de mejoramiento vegetal ha sido crucial para la adaptación de los cultivos a nuevas condiciones climáticas, además de satisfacer la creciente demanda de alimentos. Estos avances destacan el potencial de la inducción de mutaciones como una herramienta esencial para abordar los desafíos agrícolas futuros, subrayando la importancia de continuar invirtiendo en técnicas nucleares para el mejoramiento de cultivares adaptados al cambio climático y la seguridad alimentaria global.

Palabras clave: mejoramiento vegetal, variabilidad genética, FAO

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Abstract

For the genetic improvement of species of agricultural importance, it is essential to have a broad genetic base, ensuring sufficient variability to increase opportunities for selecting specific traits of interest in the field. Additionally, the use of techniques complementary to conventional breeding systems is crucial for effectively exploring the available genetic variability. Currently, there are several techniques, such as in vitro culture, genetic transformation, gene editing, marker-assisted selection, and mutation induction, among others. This review aims to synthesize the historical development, current applications, and future potential of mutation induction in crop improvement, with an emphasis on its role in adaptation to climate change and food security. Mutation induction techniques have played a key role in addressing challenges related to food security by promoting the development of new varieties for the agricultural sector in various countries. Through the analysis of the FAO/IAEA Mutant Varieties Database, it was possible to identify how mutation induction has contributed to the development of cultivars adapted to the specific needs of food security and climate. The FAO/IAEA program (https://nucleus.iaea.org), which promotes the use of nuclear techniques in agriculture, has resulted in the release of more than 3404 mutant varieties in 233 cultivated species in 75 countries. In several countries, as indicated in the MVD, the use of mutant germplasm in plant breeding programs has been crucial for adapting crops to new climatic conditions, in addition to meeting the growing demand for food. These advances highlight the potential of mutation induction as an essential tool to address future agricultural challenges, underlining the importance of continuing to invest in nuclear techniques for breeding cultivars adapted to climate change and global food security.

Keywords: plant breeding, genetic variability, FAO

INTRODUCTION

Plant breeding through mutation induction is considered a valuable advancement in agriculture, playing a crucial role in addressing global food security challenges [1,2]. It is particularly useful in crop breeding programs aimed at introducing one or two traits with limited variability within a given germplasm. This approach has primarily focused on increasing yields to meet current and future challenges, especially by enhancing crop tolerance to environmental stresses and promoting opportunities for sustainable, climate-smart agriculture [3,4].

Climate change is globally recognized as an urgent and real challenge. Nuclear techniques in plant breeding through mutation induction play a crucial role in adapting plants to climate change [4,5]. With global warming and the increased frequency of extreme weather events, developing plant varieties resistant to biotic and abiotic stresses becomes essential. These techniques contribute to enhancing the resistance of agricultural species to adverse climatic conditions, such as high temperatures, droughts, pests, and diseases [6,7,8].

Mutation induction is not a recent topic; it has been studied for nearly a century, and the first commercial crop obtained through the use of mutagenic agents dates back

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to 1930 [9]. In Indonesia, around 1936, a tobacco (*Nicotiana tabacum*) mutant was developed, producing a light-colored leaf of high quality and yield [10]. Since the 1970s, various methodologies for induced mutations using gamma rays have been developed with the goal of modifying plant material, thereby expanding the genetic variability of cultivated species and developing varieties with desirable agronomic traits, such as earliness, resistance to biotic stresses, higher yield potential, and improved quality [10,11].

This approach also aims to enhance crop performance stability under adverse environmental conditions, including rising temperatures, frequent droughts, and soil salinization [12]. Furthermore, in crop improvement, the combination of induced mutations with modern genomic and bioinformatics tools enables the establishment of genetic associations that facilitate both marker-assisted breeding and gene editing (Table 1).

TABLE 1. Historical methods for inducing mutations

1901-1904	Mutation through induced radiation in plants/animals [13].
1907	Cramer publishes extensive examples of spontaneous mutants in cultivated plants [14].
1927	*Drosophila:* proof of X-ray-induced mutation [15].
1928	First report on induced mutation in cultivated plants: barley, corn, wheat, and oats. [16,46].
1936	The first induced mutant variety of tobacco (*Nicotiana tabacum*), the 'Chlorina' variety, was developed using X-rays.
1942	The first report of induced disease resistance in a cultivated plant: X-ray-induced resistance to mildew in barley [17,18].
1944	The concept of 'Mutagenesis Breeding' was coined; the first report of chemically induced mutation [19].
1949	The first experiments on mutation in cultivated plants using gamma rays from ^{60}Co; ^{60}Co became a standard technique for mutation induction [20].
1954	The first release of a mutant variety in a vegetatively propagated crop: the tulip variety 'Faraday,' with improvements in flower color and pattern [21].
1964	The Joint FAO/IAEA Division was created with the mandate to support and promote induced mutation technologies in agricultural production, particularly addressing food security issues in developing countries [12,47].
1966	The first chemically induced mutant variety, Luther barley, was released in the USA [22].
1993	The FAO/IAEA Mutant Variety Database (*//mvgs.iaea.org*) was established in 2008 as the registry for mutant varieties of plants [12].
2000-2009	Development of high-throughput genotyping and phenotyping using automated, robotic, and computerized systems [23].
2000	Development of TILLING (Targeting Induced Local Lesions in Genomes) populations [24].
2012	The first case of genome editing in rice, known as the *rice mutant*.

The Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture provides data on officially released induced mutant materials for both seed-propagated and vegetatively propagated plants. The database, which records mutant varieties released worldwide across more than a hundred different crop species, highlights the contribution of mutation induction to global food security and crop adaptation to climate variations. For each variety, the database includes information on the type of mutagen used, the dose applied, the improved characteristics, and the available agronomic data for varieties released in different countries worldwide.

By the end of March 2025, the International Atomic Energy Agency (IAEA) reported that, through the use of induced mutation techniques in economically important cultivars, a total of 3404 mutant cultivars had been obtained across 233 crop species in more than 75 countries worldwide. Mutant varieties were developed in 16 African, 27 European, five Latin American, five North American and the Caribbean, and 21 Asian countries. Notably, over 50% of these mutants were developed using gamma rays (Fig. 1). These mutant varieties were bred for a variety of traits, including tolerance to abiotic stresses (246 mutants), resistance to biotic stresses (547), increased yield and yield components (1019), industrial and nutritional quality traits (2314), and agronomic and botanical characteristics (2420). Most of the released mutant varieties consist primarily of cereals, accounting for over 47%. Rice ranks first, representing more than 54.41% of these varieties (Fig. 2). The remaining categories include roots and tubers (0.62%), fibers (2.38%), vegetables (2.97%), forages (2.38%), fruits (2.94%), flowers/ornamentals (21.47%), legumes and pulses (13.75%), and medicinal plants (0.62%) (Fig. 2). The majority of mutant varieties were released in Asia (2089), followed by Europe (960), North America (211), Africa (82), Latin America (53), and Australia/Pacific (9) (Fig. 3).

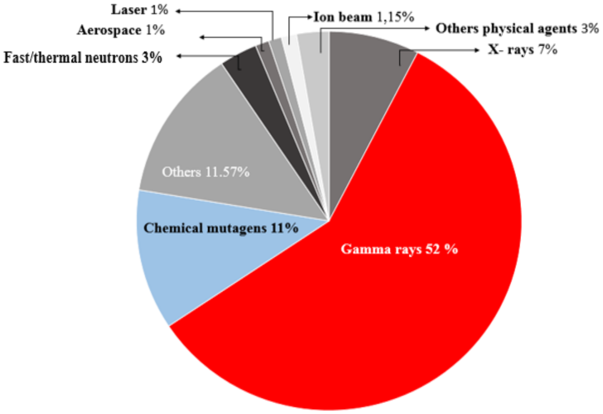

FIGURE 1: Distribution of mutagen types used in mutation induction (March 2025, FAO/IAEA MVD)

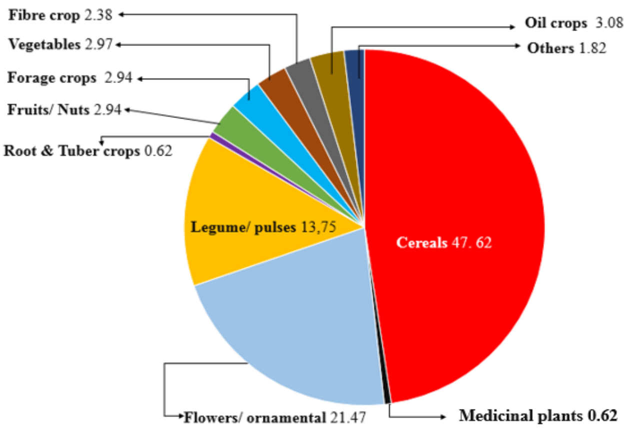

FIGURE 2: Proportion of plant varieties derived from induced mutations. Source: Mutant Variety Database and Genetic Stock Center, https://nucleus.iaea.org/, March 2025

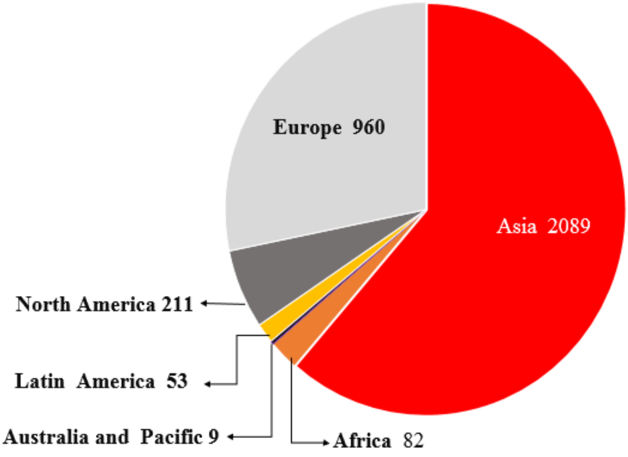

FIGURE 3: Number of registered mutant varieties per continent (March 2025, FAO/IAEA MVD)

Plant breeding is based on the observation and selection of the best individuals, aiming to identify and fix genes of interest that confer tolerance to abiotic stresses and resistance to biotic stresses within a population. In this context, the use of mutation induction techniques in genetic improvement programs is an effective strategy for generating genetic variability and enhancing population adaptation to adverse environmental conditions. This review aims to synthesize the historical development, current applications, and future potential of mutation induction in crop improvement, with an emphasis on its role in climate change adaptation and global food security.

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ROLE OF INDUCED MUTATIONS IN ENHANCING GLOBAL FOOD SECURITY

Asia

According to the FAO/IAEA database, over 61% of mutants have been released in Asia. Specifically, regarding rice, 35.42% of the mutants were released in Asia. China, Japan, and India are the three countries responsible for releasing the largest number of mutants worldwide, with the goal of increasing genetic variability and promoting food security.

In China, mutation induction strategies have played a significant role in plant breeding for over 60 years. China has officially released 825 mutant cultivars, encompassing 47 agricultural and ornamental species, covering an annual area of nine million hectares. This production increase amounts to over 1.5 million tons annually, with an estimated value of USD 500 million [25]. To date, the FAO/IAEA database has recorded a total of 296 mutant rice varieties, which have been released with superior characteristics such as semi-dwarf stature, early maturity, high yield, disease resistance/tolerance, improved grain quality, and other agronomic traits.

In India, the world's first mutant variety of cotton (*Gossypium sp.*) was released in 1948. Named 'M.A.9,' it was induced through X-rays and developed with tolerance to water stress [6,26,48].

The technique of mutation induction in plants has significantly contributed to India's food self-sufficiency and economic growth, particularly in the production of rice, peanuts, chickpeas, beans, cotton, barley, castor, and flowers/ornamentals. As of early 2024, India has approved and/or released a total of 346 mutant cultivars belonging to over 57 plant species [12]. This includes the first induced mutant variety of peanuts, 'TG 1,' developed using X-ray irradiation (750 Gy) in 1973. The main improved attributes of the mutant variety include increased seed size, maturity in 135 days, high oil content (47- 48%), and resistance to Tobacco Mosaic Virus (TMV). Following this success, 15 other Trombay (TG) peanut varieties were developed, characterized by large seeds, early maturity, and high yield.

In Japan, genetic improvement through mutation induction began in the 1960s. Techniques employed included primarily X-rays, gamma rays, ion beams, chemical agents, and in vitro culture (somaclonal variation) [5]. As a result, over 500 mutant varieties have been released, spanning more than 79 cultivar species, with approximately 46% of these being rice cultivars, according to the IAEA database [12]. The first rice cultivar was registered in 1966.

Europe

In Europe, the introduction of mutation induction techniques has played a significant role in plant breeding programs, especially for barley, wheat, maize, soybean, tobacco, ornamental species, and vegetable cultivars. This effort has resulted in the release of 960 mutant varieties across different countries [12,27,28]. Among European countries, the Russian Federation, Netherlands, and Germany stand out for employing mutation induction methods extensively, being responsible for over 58% of the released varieties.

In the Russian Federation, induced mutation began in the 1960s. Mutation induction has led to the release of 216 mutant varieties across more than 35 crop species [12]. The first mutant developed using gamma irradiation was 'Universal I' (*Glycine max* L.), officially approved in 1965. This variety was developed specifically for high yield (exceeding the initial variety by 500 kg/ha in grain yield), resistance to lodging, and suitability for both grain production and green fodder [29].

In Germany, mutation induction in barley cultivation (*Hordeum vulgare* L.) has been notably successful. A total of 66 mutant barley cultivars have been approved and/or released, including the cultivar 'Nadja,' officially approved in 1975, and the mutant variety 'Trumpf.' These varieties were developed through hybridization with the mutant 'Diamant,' obtained by irradiating seeds with X-rays (100 Gy). The main improved attributes of the mutant variety include short stature, lodging resistance, resistance to mildew, stripe rust, leaf rust, superior brewing quality, high malt quality, and high yield, surpassing that of 'Diamant.' Over 33% of the barley cultivation area has been occupied by this mutant variety [30]. The 'Trumpf' mutant has become incorporated into many barley cultivar breeding programs across numerous countries worldwide [21].

Africa

The African continent is known as the center of origin for several economically important cereals such as sorghum, millet, and African rice (*Oryza glaberrima* Steud). Mutation induction has also been successfully applied in Egypt, resulting in the introduction of two mutant varieties of dwarf stature ('semi-dwarf')—'Giza 176' (1989) and 'Sakha 101' (1997)—yielding 3.8 t ha^{-1} and 8.9 t ha^{-1}, respectively [31,32].

In the 1990s, five high-yielding varieties of sesame were released/introduced. Another significant economic success was the development of two mutant varieties of safflower (*Carthamus tinctorius* L.), which were released in 2011. These varieties exhibited high yields and resistance to diseases such as leaf spot and rust, contributing to increased income for growers in the country. The variety 'Inhas 10' was cultivated through pedigree selection and crossing between the best mutants and the local variety 'Giza 1.' An area of 10,000 hectares was planted with this sesame variety, with its commercial value estimated at around 2,996 Egyptian pounds per Fadden.

In Sudan, mutation induction methods were initiated around 25 years ago across various cultivars with the aim of increasing the productivity of several crops, including cotton, banana, tomato, sugarcane, sesame, peanuts, and cereals. These efforts were undertaken under different environmental conditions to ensure sustainable food security. The development of the mutant banana cultivar 'Albeely' was significant, showing a yield increase of over 30% and high fruit quality. It was officially approved in 2007 [33,12]. Another mutant, 'Tafra-1,' incorporated into the rainfed peanut breeding program, was released in 2018 for Sudanese farmers in water-stressed areas. This innovation improved their livelihoods and contributed to an increase in the country's economy and exports [34].

In the 1990s, Ghana began applying induced mutation breeding methods, leading to the development of the mutant variety of cassava (*Manihot esculenta* L. Crantz) called 'Tekbankye.' This variety exhibited resistance to African Cassava Mosaic Virus (ACMV), high dry matter content (40%), good cooking quality, and vigorous growth. It was developed through irradiation with gamma rays (25Gy) and was officially approved in 1997 [35,12].

North America

In North America, a total of 211 mutant varieties have been developed. According to the FAO/IAEA database (2025), over 65% of these mutants were developed in the United States, including the first semi-dwarf rice variety *Calrose 76*, which was officially approved in 1977 in California. It was developed through seed irradiation with gamma rays (250 Gy). The primary improved attribute of this mutant variety was its reduced height (95 cm) compared to the original *Calrose* cultivar, which had a height of 120 cm.

The discovery of the *Sd1* gene responsible for semi-dwarf stature in rice led to its transfer through crosses with other varieties, resulting in the development of 25 new semi-dwarf rice cultivars. Thirteen were developed in California, ten in Australia, and two in Egypt [36]. The United States is one of the leading countries in utilizing mutation induction techniques, achieving notable successes [26]. Canada and Mexico also stand out for their extensive registration of mutant varieties, emphasizing agricultural economics and ensuring food security.

Latin America

In Argentina, mutation induction has a long-standing tradition in crop improvement, primarily conducted at the "Ewald A. Favret" Institute of Genetics. Both chemical and physical mutagenesis have been pivotal in enhancing crop productivity [37,38]. A notable example is the mutant peanut variety *Colorado*, developed by irradiating seeds with X-rays (200 Gy). This variety exhibited significant increases in yield, fruit number, resistance to *Cercospora* spp., and oil content. Following its official approval, *Colorado* became a major success, occupying over 20% of the peanut-growing area in Argentina (approximately 30,000 hectares) during the 1970s [7,30].

The mutant variety 'Puita INTA-CL,' released in 2005, with high yield and herbicide resistance, occupied more than 15% of the rice cultivation area in Argentina. Furthermore, this variety was cultivated in several Latin American countries where weeds and red rice are problematic, such as Brazil, Honduras, Chile, the Dominican Republic, Costa Rica, Uruguay, Colombia, Panama, and Nicaragua. This dissemination significantly contributed to food security in these countries [26].

In Cuba, the application of nuclear methods began in the 1970s, focusing on mutation induction, which achieved numerous successes. This resulted in the development of four tomato cultivars (*Solanum lycopersicum* L.), four sugarcane varieties (*Saccharum* spp.), three soybean varieties (*Glycine max* Merrill), three hibiscus varieties (*Hibiscus* sp.), and nine rice varieties (*Oryza sativa* L.). Notably, the first mutant rice variety 'GINES' was released in 2007, developed through in vitro mutagenesis using proton radiation. Another significant rice variety, 'LP7,' officially launched in 1997, demonstrated high yield and performed well under saline stress conditions [39]. In 2007, Cuba also introduced the first mutant tomato variety 'Maybel,' which exhibited superior performance in drought conditions. It was introduced and cultivated in rural areas across different provinces of Cuba [40].

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In Peru, genetic improvement through mutation began in the 1970s with notable successes using mutagenic agents to develop improved barley varieties, one of the most important cereals in terms of area cultivation in Peru. In 1995, the first mutant barley variety (*Hordeum vulgare*) 'UNA-La Molina 95' was released, developed through seed irradiation with gamma rays (300 Gy). This mutant was characterized by its higher protein content, dwarf stature, and early maturation [12]. In 2006, a second barley variety called 'Centenário' was released and cultivated in the highlands of Peru, up to 5000 meters above sea level, significantly contributing to food security [41]. Mutation induction has also been applied to older crops in the Andean region and native Peruvian crops such as kiwicha (*Amaranthus* sp. L.). This variety, officially approved in 2006, was developed through seed irradiation with gamma rays (400 Gy), demonstrating high yield, improved grain color and size, broad adaptability, and salinity tolerance.

In Brazil, a total of 16 varieties have been obtained through induced mutation, including four varieties of rice, five of beans, four of ornamentals, two of wheat, and one of citrus (Table 2). The first mutant variety of a wheat cultivar (*Triticum aestivum* L.) was successful. In 1974, the mutant variety IAS 63 was officially approved. It was developed through hybridization, combining two mutants generated by gamma radiation (at doses between 100-300 Gy) applied to the seeds. Its distinctive characteristics include a high yield of approximately 19%, resistance to grain shattering, and increased resistance to stem rust [42,12]. Brazil is positioned as the largest producer and consumer of rice outside of Asia. It has four mutant cultivars registered in the International Atomic Energy Agency (IAEA) database (FAO/IAEA). Among these, IRAT 177 stands out, officially approved in 1988. This variety is a spontaneously mutated selection from the variety IRAT 79, obtained through seed irradiation with gamma rays (250-300 Gy). One of the key improved attributes of this mutant cultivar is increased tillering [43]. Another mutant cultivar, SCS114 Andosan, was officially approved in 2005. It was developed through seed irradiation with gamma rays (150 Gy). Its primary improved attributes include increased yield, early maturity, and improved grain quality [44]. The rice cultivar SCS118 Marques, obtained through gamma irradiation from the SCSBRS Tio Taka cultivar, was officially approved in 2013. SCS118 Marques features modern architecture, lodging resistance, a late maturation cycle, moderate resistance to blast disease, high yield potential, long grains, and very high cooking quality [45]. Another mutant cultivar is SCS121 CL, which incorporates second-generation Clearfield technology with resistance to imidazolinone herbicides. This cultivar also features a modern plant type, lodging resistance, a late maturation cycle, high yield potential, long grains, and good cooking quality, and it was officially approved in 2014 [6]. The use of mutant cultivars has immensely contributed to increasing productivity and promoting economic growth worldwide. In Brazil, however, plant improvement through mutation remains relatively insignificant, accounting for only 0.47% of the cultivars released and registered by FAO/IAEA [12].

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TABLE 2. Genotypes obtained through induced mutations in Brazil (March 8, 2025, FAO/IAEA MVD)

Variety	Year	Latin name	Common name	Character improvement
IAS 63	1974	*Triticum aestivum* L.	Wheat	Resistance to grain shading and increased resistance to stem rust
BR4	1979	*Triticum aestivum* L.	Wheat	High yield and resistance to stem rust
CAP-1070	1986	*Phaseolus vulgaris* L.	Common bean	Growth habit (bush type) and early maturity
IRAT 177	1988	*Oryza sativa* L.	Rice	Higher plant height and high tillering
FT-Paulistinha	1992	*Phaseolus vulgaris* L.	Common bean	Resistance to anthracnose, resistance to leaf spot, altered plant architecture and high yield
IAPAR 57	1992	*Phaseolus vulgaris* L.	Common bean	Resistance to Golden Mosaic Virus Disease
IAPAR 65	1993	*Phaseolus vulgaris* L.	Common bean	Resistance to Golden Mosaic Virus Disease
Cristiane	1995	*Dendranthema × grandiflora*	Chrysanthemum	White flower color
Ingrid	1995	*Dendranthema x Grandiflora*	Chrysanthemum	Pink flower color
Magali	1996	*Chrysanthemum sp.*	Chrysanthemum	Brown-colored inflorescence
Repin Rosa	1996	*Dendranthema x Grandiflora*	Chrysanthemum	Altered flower color
Campeiro	2003	*Phaseolus vulgaris* L.	Common bean	High yield and good plant architecture
SCS114 Andosan	2005	*Oryza sativa* L.	Rice	High yield, early maturity and good quality
SCS118 Marques	2013	*Oryza sativa* L.	Rice	Resistance to lodging, high yield potential and long grains with superior quality
SCS121 CL	2014	*Oryza sativa* L.	Rice	Resistant to herbicides of the imidazolinone chemical group, lodging resistance, late maturity cycle, high yield potential, long grains, and good cooking quality
IAC 2014	2016	*Citrus sinensis* L. Osbeck	Sweet orange	Seedless fruits and greater tolerance to citrus canker (in leaves and fruits)

CONCLUSIONS

The FAO-IAEA Joint Division of Nuclear Techniques in Food and Agriculture, established in 1964, has played a key role in advancing research and the application of nuclear techniques to improve food security and sustainable agricultural practices. Mutation induction can be considered a powerful tool in plant genetic improvement, playing an important role in addressing climate change and promoting global food security. In

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recent decades, mutagenesis techniques such as gamma radiation, laser irradiation, ion beams, X-rays, and fast/thermal neutrons have enabled the development of cultivars with enhanced agronomic traits, including resistance to abiotic and biotic stresses, increased productivity, and improved nutritional quality. These innovations have been crucial in adapting crops to adverse climatic conditions, which are becoming more frequent due to climate change. With a successful track record in regions such as Asia, Africa, Latin America, and Europe, mutation induction has proven effective in expanding genetic variability and creating more resilient varieties, essential for ensuring food security in a constantly changing world.

The benefits of these technologies are reflected in increased agricultural productivity, resistance to pests and diseases, and improved product quality, resulting in significant economic benefits for developing countries. As new genomic and bioinformatics tools become more accessible, the combination of these technologies with mutation induction promises to further accelerate progress in crop improvement, opening new possibilities for sustainable and resilient agriculture. The role of mutation induction will be crucial in addressing the challenges posed by climate change and ensuring global food security in the coming decades.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

Raymond Joseph: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review and editing.
Viviane Kopp da Luz: contributed to the collection, organization, and interpretation of data from the FAO/IAEA Mutant Varieties Database (MVD) and participated in writing and critically reviewing the manuscript.
Amanda Valentini Baseggio: contributed to the analysis and discussion of mutation induction techniques in plant breeding and their implications for food security and climate change adaptation
Adriana Pires Soares Bresolin: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review and editing.
Antonio Costa De Oliveira: Project administration, Resources, Validation, Supervision, Writing – review and editing.

DECLARATION OF GENERATIVE AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

For the article titled "The Contribution of Mutation Induction to Crop Improvement: Addressing Climate Change and Ensuring Food Security", the author Raymond Joseph declares that he used ChatGPT (OpenAI) to assist with language refinement, grammar correction, and typographical error correction during the preparation of the manuscript. Afterwards, the author thoroughly reviewed and edited the content as deemed necessary and takes full responsibility for the final version and the published content.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are publicly available in the FAO/IAEA Mutant Varieties Database (MVD), maintained by the Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA), and can be accessed at https://mvd.iaea.org. All information regarding mutant cultivars, crop species, and countries of origin was obtained exclusively from this database and has been properly cited in the manuscript. No proprietary or confidential datasets were used in this study.

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