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Climate resilient varietal development of diverse crops through mutation breeding in Bangladesh

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Abstract

The capability to quickly generate a considerable range of genetic variation in plants through mutation enables the mutagenesis approach extremely successful in developing climate-resistant cultivars across the entire world. In Bangladesh, plant breeders are confronted with a significant challenge in producing resilient and high-yielding cultivars rapidly capable of adapting to the changing environment in this densely populated region. Based on Mutant varieties data of Bangladesh which are available in the domain of FAO/IAEA Mutant Varieties Database (MVD), this review attempted to highlight the relevance of mutation breeding in crop variety development to adapt to changes occurring in diverse ecosystems of Bangladesh during this era of ongoing climate change. So far, seventy-eight mutant varieties of important crops have been released in Bangladesh, including rice, wheat, mustard, sesame, jute, rapeseed, tomato, black gram, chickpea, grass pea, lentil, mung bean, groundnut, and onion. Significant improvements in agronomic and botanical qualities have been made to maximize crop production. Salinity-tolerant varieties for southern coastal regions, drought-tolerant varieties for drought-prone locations, early mature varieties for flash flood escape in haor regions, submerged tolerant varieties for flooding regions and various major disease and insect resistant varieties have been generated through mutation breeding. These mutant varieties with climate-resilient traits are sustainable under different climatic circumstances, playing a key role in assuring food security in Bangladesh. Therefore, it is anticipated that mutant breeding will contribute significantly to meeting the challenges that food production will confront in the near future due to a changing climate.

Keywords: Mutagenesis, crop Improvement, mutant variety, climate change, food security

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1 Introduction

The impact of climate change on agriculture is a significant threat to the world's food production in the twenty-first century. The success of crop output is heavily reliant on both genetic foundations and favorable climatic conditions. Unfortunately, changing environmental factors directly affect agricultural production, hindering food security stability (Ahmed et al., 2022; Acevedo et al., 2020; Kharkwal and Shu, 2009). To combat this issue and ensure sufficient food supply for the growing population, plant breeders are working to develop crop types that can adapt to changing climatic conditions. To achieve this, a wide range of base genes is necessary to create genotypic and phenotypic variability suitable for various ecosystems. Mutagenesis is an effective strategy to rapidly increase genetic variation among crop species, allowing them to adapt to new environments with different geographic, physical, and biological properties (Bado et al., 2015). This genetic diversity produced by mutations is crucial for developing climate-resilient crop varieties with increased functionalities. Such crops can maintain or improve agricultural yields under both abiotic and biotic stress, providing adaptation in a range of climatic circumstances (Acevedo et al., 2020). Therefore, mutation breeding is essential for plant breeding in the twenty-first century, particularly for developing climate-resilient crops (Bado et al., 2015).

In the global context, mutation breeding has become an essential factor in maintaining food security under climate change scenarios. These varieties have a significant impact on environmentally sustainable agriculture worldwide and have helped address issues surrounding food and nutritional security (Ahloowalia et al., 2004; Kharkwal and Shu, 2009). Currently, there are 3388 mutant varieties of 231 species that have been developed through mutation breeding and are contributing to global food security (IAEA, 2022). Asia has the highest number of mutant varieties (2087), followed by Europe (960), North America (211), Africa (82), Latin America (53), and Australia and the Pacific (9), respectively (IAEA, 2022). Mutation breeding is applied to improve traits in various crops such as pulses (Solanki et al., 2011), legumes (Micke, 1988), cereals (Scarascia-Mugnozza et al., 1993; Viana et al., 2019), oilseeds (Jayaramachandran et al., 2020), ornamental (Ibrahim et al., 2018) that can adapt to different climatic conditions. The top six crops for which mutant varieties were developed are rice (873), barley (307), chrysanthemum (285), wheat (265), soybean (182), and maize (89) (IAEA, 2022). Through mutation breeding, various agronomic and botanic traits, quality and nutrition traits, resilience to biotic stress, resistance to abiotic stress, yield, and yield contributing traits have been improved, allowing crops to adapt to changing ecosystems (IAEA, 2022). The significant contribution of mutation breeding in crop improvement is evident from several studies (Scarascia-Mugnozza et al., 1993; Mba, 2013; Wani et al., 2014; Bado et al., 2015; Oladosu et al., 2015; Pandit et al., 2021).

Since 1995, Bangladesh has consistently ranked sixth among the nations most vulnerable to the effects of climate change (Ahmed et al., 2022). Climate change poses a significant obstacle to increasing agricultural productivity in Bangladesh. The country is currently experiencing a shift in seasonal climate patterns, with the annual calendar moving from six to four seasons (Islam and Kotani, 2013). Additionally, climate change has caused sea levels to rise, resulting in a reduction of arable land in southern Bangladesh. The unpredictability and gradual changes in temperature, precipitation, and natural disasters have also increased, along with the intensity of attacks from pests and diseases. At the same time, the country's population density is increasing, leading to industrialization and a gradual shrinking of agricultural land. These factors endanger the nation's food security and affect crop productivity. Meeting the food demand of Bangladesh's large population while ensuring food supply is a significant challenge for the country's agriculture now and in the future, given the issue of climate change.

Plant breeders in Bangladesh must take into account the significant functional impact of climate on various ecosystems when developing climate-resilient varieties. According to studies conducted by Rahman et al. (2009), and Sikder and Xiaoying (2014). climate change has had an impact on various ecosystems in Bangladesh, including:

- The floodplain ecosystem is affected by various factors such as the flooding characteristics, inundation depth and duration, flood water receding period, frequency of floods, and coverage of flooded area during the monsoon season.
- Coastal ecosystems are experiencing various changes, such as growth in salinized areas, increased salinity concentration, drainage congestion, coastal floods, and cyclones/storm surges.
- In the Haor Basin, there have been changes in attributes, flash flood timing, and recession length.
- In hilly areas, rainfall distribution and intensity can vary and may cause erosion of the topsoil.

In Bangladesh, like in many other countries, mutation breeding is being used to combat the effects of climate change on agriculture. Over a long period of time, Bangladesh has developed 78 mutant varieties of major crops (IAEA, 2022). The goal of mutation breeding is to create sustainable crops that can adapt to changing climate conditions. In particular, significant success has been achieved in developing mutant varieties of the main food crop in Bangladesh, rice (Azad et al., 2012). This study aims to explore the importance of mutation breeding in developing climate-resilient crops by discussing the patterns of mutant variety release, the mutagenic approach used for varietal development, and crop trait enhancement in the context of Bangladesh.

2 Overview of mutant variety development in Bangladesh

Over the years, Bangladesh has developed mutant varieties of different crops to improve their economic characteristics (Fig. 1). As of now, a total of seventy-eight mutant crop varieties from sixteen important crops have been released in Bangladesh, including rice, wheat, Indian mustard, oriental mustard, rapeseed, sesame, tossa jute, jute, tomato, black gram, chickpea, grass pea, lentil, mungbean, groundnut, and onion. These crops are highly valuable and have a significant socioeconomic impact, directly linked to the country's food security. They possess climate resilience traits, such as improved agronomic and botanical traits, nutrition and quality traits, resistance to biotic and abiotic stress, yield and yield contributing traits.

The categorization of the mutant crops on the basis of their primary uses, have shown that most of the mutants crops belong to legume and pulse crops and the percentage is 47.44% of the total mutant varieties. Cereals come in second at 17.95%, followed by edible oil at 16.67%, nuts at 2.56%, food vegetables at 7.69%, fiber crops at 5.13%, and roots and tuber crops at 2.56% (Fig. 1A). Rice, which is a staple food in Bangladesh, has the highest number of mutant varieties (13) and makes up 16.67% of all mutant varieties. Chickpeas have the second-highest number of varieties (10), followed by mung beans and lentils with 9 each. The remaining crops, in descending order, are groundnut (2.56%), rapeseed (5.13%), sesame (5.13%), tomato (5.13%), tossa jute (5.13%), jute (1.3%), oriental mustard (3.85%), Indian mustard (2.56%), onion (2.56%), black gram (1.3%), and wheat (1.3%). Most of these mutant varieties are self-pollinating crops, accounting for 92.3% of the total (IAEA, 2022).

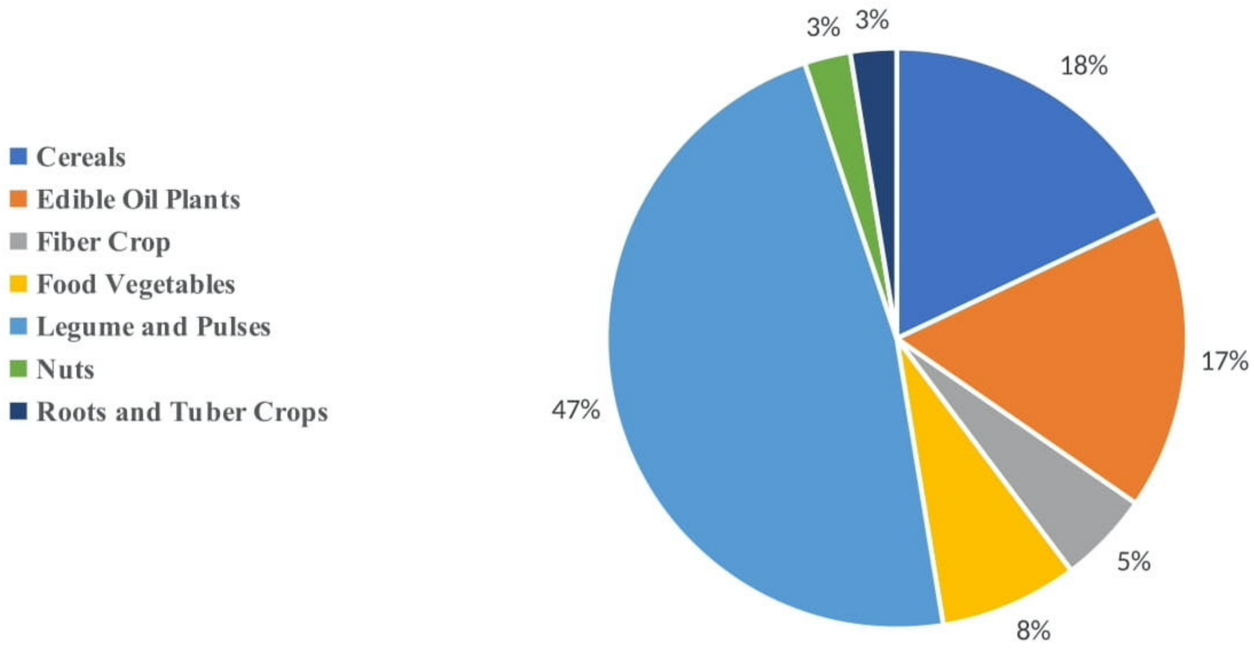
3 Trend of mutant variety release in Bangladesh

The mutant varieties of different crops in Bangladesh released during the years 1970 to 2022 are shown in Fig. 2. The first mutant crop in Bangladesh was Iratom 24, a rice variety released by the Bangladesh Institute of Nuclear Agriculture (BINA) in 1970. In 1974, the same institute released three varieties of tossa jute, named Atompat-28, Atompat-36, and Atompat-38. The first mutant species of Chickpea, Hypochola, was released in 1981, and the first oriental mustard variety, Shambal (BAU-M/248), was released by Bangladesh Agricultural University in 1984. In 1987, another mutant rice variety called Binasail was released. Oriental mustard varieties Safal and Agrani were released in 1991, followed by tomato variety Bahar and mungbean variety Binamoog-1 in 1992. Two years later in 1994, the black gram mutant variety Binamash-1 and another mungbean mutant variety Binamoog-2 were released. Additionally, in 1995 BINA introduced five new varieties of three crops which included three rice varieties; Binadhan-4, Binadhan-5, and Binadhan-6, a mung bean variety; Binamoog-5, and Binasola-2, a chickpea variety. Several mutant varieties were developed by BINA in 1997, including the jute variety Binadeshipat 2, two rapeseed varieties named Binasharisha-2 and Binasharisha-3, two tomato varieties Binatomato-3 and Binatomato-3, and two mung bean varieties Binamoog-3 and Binamoog-4. From 2000 to 2022, a total of 53 mutant varieties of different crops were developed in Bangladesh by BINA. For instance, in 2000, three groundnut varieties were released, named Binachinabadam-1, Binachinabadam-2, and Binachinabadam-3 and in 2001, the grass pea variety Binakheshari-1, chickpea variety Binamasur-1, and two chickpea varieties Binachola-3, and Binachola-4 were released. Two rapeseed varieties, Binasarisha-5 and Binasarisha-6, were released in 2002, and the mutant tossa jute variety Binapatsak-1 was released in 2003. In 2005, two lentil varieties named Binamasur-2, Binamasur-3 and two mung bean varieties Binamoog-6, and Binamoog-7 were released. From 2007 to 2010, more mutant varieties were released, such as rice variety Binadhan-7, groundnut variety Binachinabadam-4, chickpea varieties Binachola-5 and Binachola-6, and mung bean variety Binamoog-8. In 2011, varieties of groundnut, lentil, indian mustard, and sesame were released, named Binachinabadam-5, Binachinabadam-6, Binamasur-5, Binamasur-6, and Binatil-2. Only one rice variety, Binadhan-9, was released in 2012. In 2013, more varieties were released, including rice varieties Binadhan-13 and Binadhan-14, chickpea varieties Binachola-7 and Binachola-8, rapeseed variety Binasarisha-9, and sesame variety Binatil-3. The year 2014 saw the release of four new mutant varieties: Binachinabadam-7 and Binachinabadam-9 the salt tolerant groundnut varieties, and Binamasur-8 and Binamasur-9 for lentil. The Binadhan-18 rice variety was released in 2015, followed by the release of the Binagom-1 the first salt tolerant wheat mutant variety in 2016. That same year, three other varieties were released: Binachola-9 and Binachola-10, both are chickpea varieties, and Binatil-4, a sesame variety. In 2017, three new varieties were released: Binadhan-19; a rice variety, Binamasur-11; a lentil variety, and Binamug-9; a mung bean variety. The onion mutant varieties, Binapiaz-1 and Binapiaz-2, were released in 2018. Recently, new lentil variety Binamasur-12 and rice variety Binadhan-25 were released in 2021 and 2022 respectively by BINA.

4 Mutagenic approaches for varietal development of different crops

Various mutagenesis techniques are used to improve desirable traits when developing new plant varieties. The selection of a suitable plant is based on the intended outcome before applying a mutagenic agent to plant parts like cells, seedlings, or seeds. Physical and chemical mutagenic agents are the two primary groups used. Physical mutagens like alpha and beta particles, electromagnetic and cosmic radiation, x-rays, and ultraviolet light are commonly used for varietal development (Oladosu et al., 2015; Mba, 2013). Chemical mutagens like base analogs, alkylating agents, and intercalating agents are also used, but physical mutagens are more widely used globally (Oladosu et al., 2015). In Bangladesh, 89.74% of

(A)



(B)

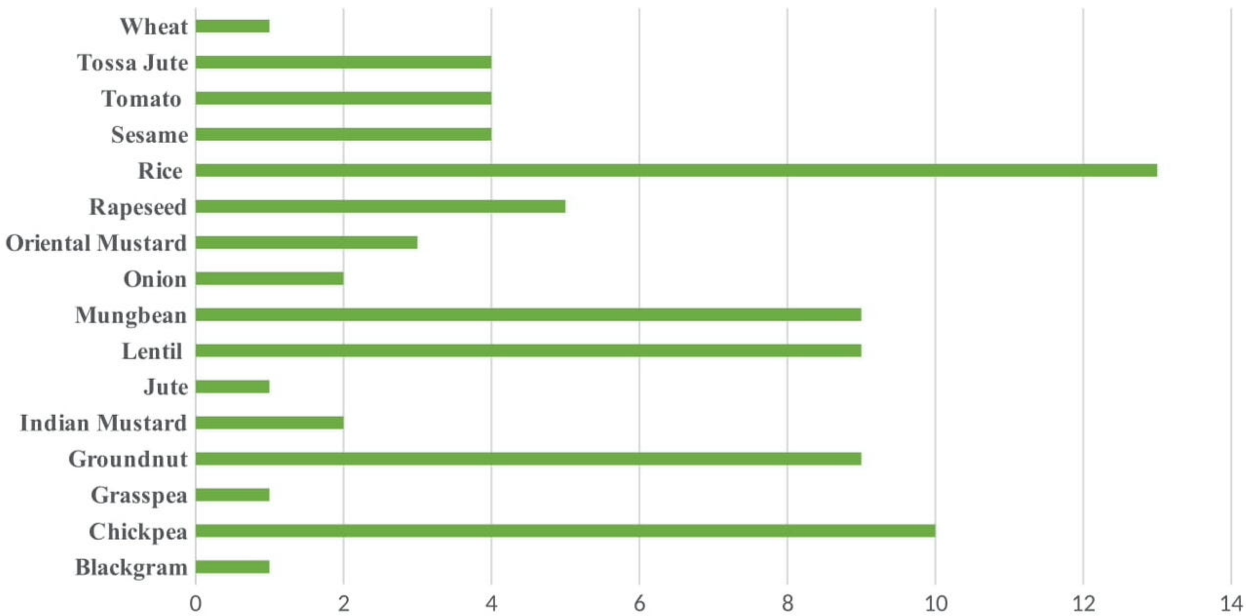


Figure 1. Overview of mutant variety development in Bangladesh. (A) Percentage of mutant crop varieties based on their uses, and (B) Frequency of mutant varieties development of different crops. Source: Calculated from FAO/IAEE Mutant Varieties Database (MVD) (IAEA, 2022)

mutant varieties have been developed using physical mutagenesis, with gamma radiation being the dominant physical mutagen used (IAEA, 2022). Mutagenic treatments create a variety of desired and undesired genetic variations, which are subsequently identified by screening by growing them in different generations. Once the desired trait is found to be stable in the progeny, the mutants undergo field trials. This process is known as using an induced mutant directly and has resulted in the development of the majority of the mutant varieties (73.1%) in Bangladesh. If mutants lack the desired traits, they undergo repeated exposure to mutagen in several generations, which is known as mutagenic treatment in various generations. Similar to the mutagenic treatment of breeding material, F1, F2, and other offspring are subjected to mutagenic treatments following crossbreeding. Another way is crossing one mutant with a different plant to pass on the desired trait to the offspring. If the desired trait is not formed, these offspring are also given mutagenic therapy. Plant breeders use diverse processes to increase crop traits in the direction of their objectives. Table 1 provides detailed information on the mutagenic approach to trait improvement of various crops in Bangladesh.

4.1 Mutant black gram

The Binamash-1 mutant variety of black gram was created using physical mutagenesis. To develop this variety, the Seed of BINA Acc.B-10 was exposed to Gamma (γ) radiation with a dose of 600 Gy.

4.2 Mutant chickpea

Ten mutant varieties of chickpeas have been released in Bangladesh, as mentioned by the FAO/IAEA Mutant Varieties Database (MVD) (IAEA, 2022). These are Hypochola (Binachola-1), Binachola-2, Binachola-3, Binachola-4, Binachola-5, Binachola-6, Binachola-7, Binachola-8, Binachola-9, and Binachola-10. All of these varieties were created using ionizing γ rays as a physical mutagen. Hypochola, Binachola-2, Binachola-3, and Binachola-7 were developed by exposing them to a single dose of 200 Gy of γ rays. Binachola-3 was formed by irradiating dried seeds of the rare genotype G-97 with 200 Gy of γ radiation. The mutant variety Binachola-7 was developed by irradiation of Binachola-2 seds with gamma rays (200 Gy) On the other hand, Binachola-5, Binachola-9, and Binachola-10 were created using multiple doses of γ rays. Binachola-5 was developed by exposing Hypochola hyprosola seeds to multiple doses (150 Gy, 200 Gy, 250 Gy, 300 Gy, 250 Gy, and 400 Gy) of γ rays. Binachola-9 was produced by exposing Binasola Binachola-2 seeds to several doses of γ rays (200 Gy, 300 Gy, and 400 Gy). Binasola Binachola-10 was created by irradiating advanced mutant CPM-850 with different doses of radiation (200 Gy, 300 Gy, and 400 Gy). Additonally induced mutant used in hybridization procedures to create other mutant chickpea varieties, including Binachola-4, Binachola-6, and Binachola-8. Binachola-4 was created by exposing seeds to 200 Gy of γ rays produced from a cross between the ICRISAT line K-850 and a mutant variety called Hyposola. Binasola Binachola-6 was developed by irradiating seeds with gamma rays (200 Gy) produced from a cross between the ICRISAT line K-850 and one advanced mutant G-299. And, Binachola-8 was developed by crossing the mutant variety Hypochola with the ICRISAT line K-850.

4.3 Mutant grass pea

Currently, only the Binakheashari-1 mutant variety of grass peas has been introduced in Bangladesh. This variety was created by subjecting the seed of a local genotype, L-1, to gamma (γ) radiation at a dose of 250 Gy (IAEA, 2022).

4.4 Mutant groundnut

High-yielding mutant varieties of groundnut with medium-sized pod and kernel has been developed through the exposure of gamma radiation over several generations or with irradiation of varying amount of radiation (Azad et al., 2014). Binachinabadam-1, Binachinabadam-2, and Binachinabadam-3 were developed using 200 Gy dose of γ irradiation. Binachinabadam-4, Binachinabadam-5, Binachinabadam-6, and Binachinabadam-7 were produced by irradiation with 200 Gy gamma rays from Dacca-1, a popular local groundnut cultivar with small pod sizes, (Azad et al., 2010). Whereas Binachinabadam-5 and Binachinabadam-6 has been developed through exposure to γ radiation over several generations (Azad et al., 2014). Additionally, Binachinabadam-9 and Binachinabadam-10 were obtained from PK-1 seeds treated with γ radiation doses of 250 Gy and 150 Gy, respectively. Mut-3 was produced by exposing Dacca-1 seeds to γ rays, and Mut-6, a plant with unique traits, was discovered later in the field. Mut-6 was treated with a 250 Gy dose of γ radiation, leading to the formation of the Binachinabadam-5 and Binachinabadam-6 varieties (IAEA, 2022).

4.5 Mutant Indian mustard

Mutant varieties of Indian mustard were created by irradiating with multiple dosages of γ rays as explained in the study of Malek et al. (2012). According to their research, seeds of the well-adapted and popular mustard variety BARIsarisha-11 were irradiated with gamma ray using 60Co gamma cells to produce two high yielding mustard varieties, Binasarisha-7

Table 1. Mutagenic approaches used for development of mutant crop varieties in Bangladesh

Crop name	Variety name	Mutagen	Doses	Applied on	Parent genotype	MDT
Black gram	Binamash-1	Physical	γ rays (600 Gy)	Seed	BINA Acc.B-10	DU
Chickpea	Binasola-10	Physical	γ rays (200,300, and 400 Gy)	Seed	CPM-850	DU
Chickpea	Binasola-2	Physical	–	–	–	–
Chickpea	Binasola-3	Physical	γ rays (200 Gy)	Seed	G-97	DU
Chickpea	Binasola-4	Physical	γ rays (200 Gy)	Seed	Hyprosola,K-850	CM
Chickpea	Binasola-5	Physical	γ rays (150, 200, 250, 300, 350, and 400 Gy)	Seed	Hyprosola	DU
Chickpea	Binasola-6	Physical	γ rays (200 Gy)	Seed	K-850,G-299	CM
Chickpea	Binasola-7	Physical	γ rays (200 Gy)	Seed	–	DU
Chickpea	Binasola-8	Physical	γ rays (200 Gy)	Seed	Hyprosola, K-850	CM
Chickpea	Binasola-9	Physical	γ rays (200, 300, and 400 Gy)	Seed	Binasola-2	DU
Chickpea	Hyprosola	Physical	γ rays (200 Gy)	–	–	DU
Grass pea	Binakhesari-1	Physical	γ rays (250 Gy)	Seed	L-1	DU
Groundnut	BINA Chinabadam-1	Physical	γ rays (200 Gy)	Seed	–	DU
Groundnut	BINA Chinabadam-10	Physical	γ rays (150 Gy)	Seed	–	DU
Groundnut	BINA Chinabadam-2	Physical	γ rays	Seed	–	DU
Groundnut	BINA Chinabadam-3	Physical	γ rays (200 Gy)	Seed	–	DU
Groundnut	BINA Chinabadam-4	Physical	γ rays (200 Gy)	Seed	–	DU
Groundnut	BINA Chinabadam-5	Physical	γ rays (250 Gy)	Seed	–	DU
Groundnut	BINA Chinabadam-6	Physical	γ rays (250 Gy)	Seed	–	–
Groundnut	BINA Chinabadam-7	Physical	γ rays (200 Gy)	Seed	–	–
Groundnut	BINA Chinabadam-9	Physical	γ rays (250 Gy)	Seed	–	DU
Indian mustard	Binasarisha-7	Physical	γ rays (600, 700, 800, and 900 Gy)	Seed	MM-10-4	DU
Indian mustard	Binasarisha-8	Physical	γ rays (600, 700, 800, and 900 Gy)	Seed	MM-08-4	DU
Jute	Binadeshipat-2	Chemical	Sodium azide (12 mM)	Seed	–	DU
Lentil	Binamasur-1	Chemical	Datura Seed Extract	Seed	L-5	DU
Lentil	Binamasur-11	Physical	γ rays (200 Gy)	Seed	BARI masur-4	DU
Lentil	Binamasur-12	Physical	γ rays (250 Gy)	Seed	BARI masur-6	DU
Lentil	Binamasur-2	Physical	γ rays (200 Gy)	Seed	Utfala	DU
Lentil	Binamasur-3	Chemical	0.5% EMS	Seed	L-5	DU
Lentil	Binamasur-5	Physical	γ rays (200 Gy)	Seed	BARI masur-4	DU
Lentil	Binamasur-6	Physical	γ rays (250 Gy)	Seed	BARI masur-4	DU
Lentil	Binamasur-8	Physical	γ rays (200 Gy)	Seed	BARI masur-4	DU
Lentil	Binamasur-9	Physical	γ rays (200 Gy)	Seed	BARI masur-4	DU
Mungbean	Binamoog-1	–	–	–	–	–
Mungbean	Binamoog-2	Physical	γ rays	Seed	MB-55(4)	CM
Mungbean	Binamoog-3	Physical	γ rays (200 Gy)	Seed	MB55-4, AURDC line V1560D	BM
Mungbean	Binamoog-4	Physical	γ rays (200 Gy)	Seed	MB55-4, AURDC line V1560D	BM
Mungbean	Binamoog-5	Physical	γ rays (200 Gy)	Seed	MB55-4, AURDC line V1560D	BM
Mungbean	Binamoog-6	Physical	γ rays (400 Gy)	Seed	VC-6173-10	DU
Mungbean	Binamoog-7	Chemical	0.75% EMS	Seed	Binamoog-2	DU
Mungbean	Binamoog-8	Physical	γ rays (400 Gy)	Seed	MB-149	DU
Mungbean	Binamoog-9	Physical	γ rays (400 Gy)	Seed	BARI Mung-6	DU
Onion	Binapiaz-1	Physical	γ rays (75 Gy)	Seed	BARI Piaz-2	–
Onion	Binapiaz-2	Physical	γ rays (100 Gy)	Seed and Bulb	BARI Piaz-2	DU
Oriental mustard	Agrani	Physical	γ rays (700 Gy)	Seed	–	DU
Oriental mustard	Safal	Physical	γ rays (700 Gy)	Seed	–	DU
Oriental mustard	Shambal(BAU-M/248)	Chemical	0.64% EMS	Seed	–	DU
Rape seed	Binasarisha-5	Physical	γ rays	Seed	–	DU
Rape seed	Binasarisha-6	Physical	γ rays	Seed	–	DU
Rape seed	Binasarisha-9	Physical	γ rays (600, 700, 800, and 900 Gy)	Seed	Binasarisha-4	DU
Rape seed	Binasharisha-3	Physical	γ rays (800 Gy)	Seed	–	DU
Rape seed	Binasharisha-4	Physical	γ rays (800 Gy)	Seed	–	DU
Rice	BINA dhan 25	Physical	γ rays (40 Gy)	Seed	–	DU
Rice	Binadhan-13	Physical	γ rays (150 Gy), Datura seed extract	Seed	–	BM
Rice	Binadhan-14	Physical	Carbon ion beams	Seed	Ashfal	BM
Rice	Binadhan-18	Physical	γ rays (40 Gy)	Seed	–	BM
Rice	Binadhan-19	Physical	γ rays (40 Gy)	Seed	–	DU
Rice	Binadhan-20	Physical	γ rays	Seed	Binasail, Red rice	DU
Rice	Binadhan-4	Physical	γ rays (300 Gy)	Seed	–	DU
Rice	Binadhan-5	Physical	γ rays (300 Gy)	Seed	–	DU
Rice	Binadhan-6	Physical	γ rays (300 Gy)	Seed	–	CM
Rice	Binadhan-7	Physical	γ rays	Seed	–	DU
Rice	Binadhan-9	Physical	γ rays	Seed	Malaysian mutant line, Kalizira	CM
Rice	Binasail	Physical	γ rays	Seed	–	DU
Rice	Iratom 24	Physical	γ rays	Seed	–	DU
Sesame	Binatil-1	Physical	γ rays	Seed	–	DU
Sesame	Binatil-2	Physical	γ rays (500,600,700, and 800 Gy)	Seed	T-6	DU
Sesame	Binatil-3	Physical	γ rays (500,600,700, and 800 Gy)	Seed	Binatil-1	DU
Sesame	Binatil-4	Physical	γ rays (500,600,700, and 800 Gy)	Seed	T-6	DU
Tomato	Bahar	Physical	γ rays (250 Gy)	Seed	N/A	CM
Tomato	Binatomato-13	Physical	γ rays (370 Gy)	Seed	TM-5	DU
Tomato	Binatomato-2	Physical	γ rays (100 Gy)		–	BM
Tomato	Binatomato-3	Physical	γ rays (100 Gy)	Seed	–	BM
Tossa jute	Atompat-28	Physical	γ rays	Seed	D-154	DU
Tossa jute	Atompat-36	Physical	γ rays	Seed	D-154	DU
Tossa jute	Atompat-38	Physical	γ rays	Seed	D-154	DU
Tossa jute	Binapatshak-1	–	–	–	–	–
Wheat	Binagom-1	Physical	γ rays	Seed	–	DU

MDT: mutant development type, DU: direct use, CM: crossing with mutant, BM: treatment on breeding material; Source: FAO/IAEA Mutant Varieties Database (MVD) (IAEA, 2022) and Binasarisha-8, respectively for commercial cultivation in 2011.

4.6 Mutant jute

The Binadeshipat-2 mutant strain was created using the chemical mutagen sodium azide (NaN3) at a dose of 12 mM (IAEA, 2022).

4.7 Mutant lentil

Bangladesh Institute of Nuclear Agriculture (BINA) has developed nine lentil varieties through chemical and physical mutagenesis, with each cultivar showcasing unique characteristics (Khatun et al., 21021). According to the FAO/ IAEA Mutant variety database, the well-known lentil cultivar BARI masur-4, locally known as Surma was primarily irradiated with γ-rays to produce most of the varieties. For instance, Binamasur-5, Binamasur-8, Binamasur-9, and Binamasur-11 were developed by irradiating BARI masur-4 with 200 Gy of γ radiation. Similarly, Binamasur-6 and Binamasur-12 were created by exposing BARI masur-4 to 250 Gy of γ radiation. Binamasur-2 was created by directly exposing dried seeds of the local utfala genotype to 200 Gy of γ radiation. On the other hand, chemical mutagens were used to produce Binamasur-1 and Binamasur-3. Binamasur-1 was developed by using Datura seed extract as a chemical mutagen on wet seeds of the local genotype L-5. Additionally, bBinamasur-3 was produced by soaking seeds of the local genotype L-5 in a chemical mutagen containing 0.5% EMS.

4.8 Mutant mung bean

In Bangladesh, there are nine mutant mungbean varieties: Binamoog-1, Binamoog-2, Binamoog-3, Binamoog-4, Binamoog-5, Binamoog-6, Binamoog-7, Binamoog-8, and Binamoog-9. Some of these varieties, such as Binamoog-2, Binamoog-3, Binamoog-4, and Binamoog-5, were created using induced mutations during hybridization, while others were simply selected as varieties. Most of the mutant lentil types were created using ionizing γ rays at different doses. Binamoog-6, Binamoog-8, and Binamoog-9, however, were developed by irradiating the seed of the advanced line. For example, Binamoog-6 was created by subjecting an advanced mutant line, VC-6173-10, to 400 Gy of γ irradiation. Binamoog-8 was developed through the use of γ rays (400Gy) to induce the seed of the advanced line MB-149. Binamoog-9 was developed by using γ rays (400 Gy) on seeds of BARI Mung-6. Binamoog-2 was created by hybridizing with the γ-ray-induced mutant MB-55. Binamoog-3, Binamoog-4, and Binamoog-5 were developed through irradiating hybrid seeds. Binamoog-3 was created by irradiating hybrid seeds from crossbreeding (Mutant MB55-4 x AURDC line). Mutant MB-55(4) was developed through irradiation of seeds with γ rays (200Gy). In the case of Binamoog-4, γ rays caused the mutant MB-55(4) (200 Gy) which was then crossbred. Seeds produced through crosses were irradiated by γ ray, resulting in the development of Binamoog-3. Binamoog-5 was created by irradiating hybrid seeds from crossbreeding (Mutant MB55-4 $\times$ AURDC line). Mutant MB-55(4) was developed by using γ ray irradiation with a dose of 200 Gy. Only Binamoog-7 was created with the use of a chemical mutagen. Binamoog-7 was developed by treating seeds from Binamoog-2 with a chemical mutagen containing 0.75 percent EMS (IAEA, 2022).

4.9 Mutant onion

By exposing BARI piaz-2 seeds to varying doses of γ radiation, new onion varieties were created: Binapiaz-1 and Binapiaz-2.

4.10 Mutant oriental mustard

New types of mutant oriental mustard varieties have been developed using chemical and physical mutagens. The variants known as Agrani and Safal were produced by exposing the seeds to γ radiation of 700 Gy, while the variant called Shambal was created by applying a chemical mutagen with 0.64% EMS to the seeds (IAEA, 2022).

4.11 Mutant rapeseed

In the creation of different rapeseed varieties, a range of γ ray treatments were utilized, including single doses and varying dosages. Through exposure to 800 Gy of γ rays, mutant varieties such as Binasharisha-3, Binasharisha-4, Binasharisha-5, and Binasharisha-6 were developed. Additionally, Binasarisha-9 was created by subjecting seeds from the Binasarisha-4 type to different doses of γ radiation, ranging from 600 Gy to 900 Gy (IAEA, 2022).

4.12 Mutant rice

New varieties of rice were created through exposure to γ rays and carbon ion beams (IAEA, 2022). For example, the mutant strains Iratom 24, Binasail, and Binadhan-7 emerged after seed exposure to γ rays. Carbon ion beams were used to develop Binadhan-14, Binadhan-18, Binadhan-19, and Binadhan-40. Binadhan-14 and Binadhan-18 were created by inducing mutations in Ashfal and BRRIdhan-29, respectively. Binadhan-19 resulted from bombarding NERICA-10 seeds with carbon ion beams. Some varieties were developed through crossing local cultivars and mutant plants, such as Binadhan-9 (which crossed the low-yielding Kalozira plant with the high-producing mutant Y-1281) and Binadhan-20 (which crossed the Binasail mutant with Red Rice). Other varieties, such as Binadhan-4, Binadhan-5, Binadhan-6, and Binadhan-13, were created by exposing seeds to γ rays and chemical mutagens. For example, Binadhan-13 resulted from irradiating fragrant Kalizira rice seeds with γ rays (150 Gy) after soaking them in Datura seed extract for 18 hours. BINA dhan-25, a variant of BRRI dhan-29, was also produced through mutagenesis.

4.13 Mutant sesame

New types of sesame, called Binatil-1, Binatil-2, Binatil-3, and Binatil-4, were developed by exposing T-6 sesame seeds to γ radiation at varying levels (500, 600, 700, and 800 Gy). Binatil-2 and Binatil-4 were produced in this manner. Binatil-1 seeds were also irradiated at the same levels to create Binatil-3 (IAEA, 2022).

4.14 Mutant tomato

The development of mutant tomato varieties involved exposing Binatomato-7 seeds to 370 Gy of γ rays, which resulted in the creation of Binatomato-13 (IEAE, 2022). To create the mutant varieties Binatomato-2 and Binatomato-3, the method used was to treat the hybrid seeds from the F1 generation with γ radiation (100 Gy). The breeding program also employed mutant varieties, such as the Bahar variety, which was created by crossing with the dwarf mutant Anobik. The Anobik mutant was developed by exposing the local Oxheart variety to 250 Gy of gamma rays (IAEA, 2022).

4.15 Mutant tossa jute

The mutant Tossa jute varieties found in Bangladesh were created by exposing the seeds of the D-154 variety to γ rays. As a result, varieties such as Atompat-28, Atompat-36 were developed through this process of irradiation. Seeds of a wild cultivated variety, CVL-1 were irradiated with gamma rays and EMS to induce genetic variability, resulting in the development of Atompat-38 (Shamsuzzaman et al., 2005).

4.16 Mutant wheat

According to the domain of the FAO/IAEA Mutant Varieties Database (MVD) Binagom-1, a type of wheat, introduced from the seeds of a salt tolerant segregating mutant population, L-880 of wheat collected from NIAB, Pakistan. Binagom-1 is suitable for commercial cultivation in the saline and non-saline areas of Bangladesh (Mohammad et al., 2018).

5 Development of climate resilient traits in various crops

Plants possess different traits that are essential in managing issues caused by climate change. Early maturing traits increase cropping intensity, adapt to diverse cropping systems, and complete their life cycle quickly. Late maturing traits are adaptable to agricultural systems that can avoid regional extreme weather events. Synchronous maturing traits ensure harvestable crops at the same time, reducing crop loss due to unexpected weather events. Disease-tolerant traits help crops survive against major diseases or the emergence of new diseases resulting from climate change. Insect tolerance traits are vital in surviving against the intensity of major or new insects that may arise due to global warming. Salt-tolerant traits can assist in overcoming farming challenges in Bangladesh's coastal areas caused by salinity. Lodging tolerant traits become significant traits for Bangladesh as severe rains, storms, and hailstorms caused by climate change can lead to plant lodging. The solution to this issue is lodging-resistant plants. Drought-resistant plants are required to solve the challenge brought on by an increase in drought severity caused by climate change. Flooding due to rainfall intensity increase caused by climate change, especially in the haor region, leads to immense deterioration of agricultural production. Certain plants can endure flooding and survive in waterlogged conditions, which is crucial in addressing this problem. Rahman et al. (2009) conducted a study that highlighted climate risks across various agroecological regions in Bangladesh, as depicted in Fig. 3. This provides valuable insight into the existing climatic challenges in Bangladesh as well as the economic improvements that can be made. Table 2 contains detailed information on how mutation breeding has enhanced the characteristics of different crops in Bangladesh.

5.1 Improving traits in black gram

Many black gram cultivars have been improved through mutagenesis, resulting in varieties that have higher yields and greater disease resistance. One such variety is Binamash-1, which outperforms other black gram varieties in terms of yield. Black gram also needs to mature early and synchronously to cope with unpredictable weather patterns and minimize losses. Mutation breeding has helped create early-maturing varieties like Binamash-1, which is highly efficient in increasing production. Disease and insect attacks pose a serious threat to crop production, but Binamash-1, the mutant black gram variety has been found to resist two major diseases, yellow mosaic virus diseases (YMV) and Cercospora leaf spot (CLS) (Shaikh and Majid, 1995). As a mutant strain,

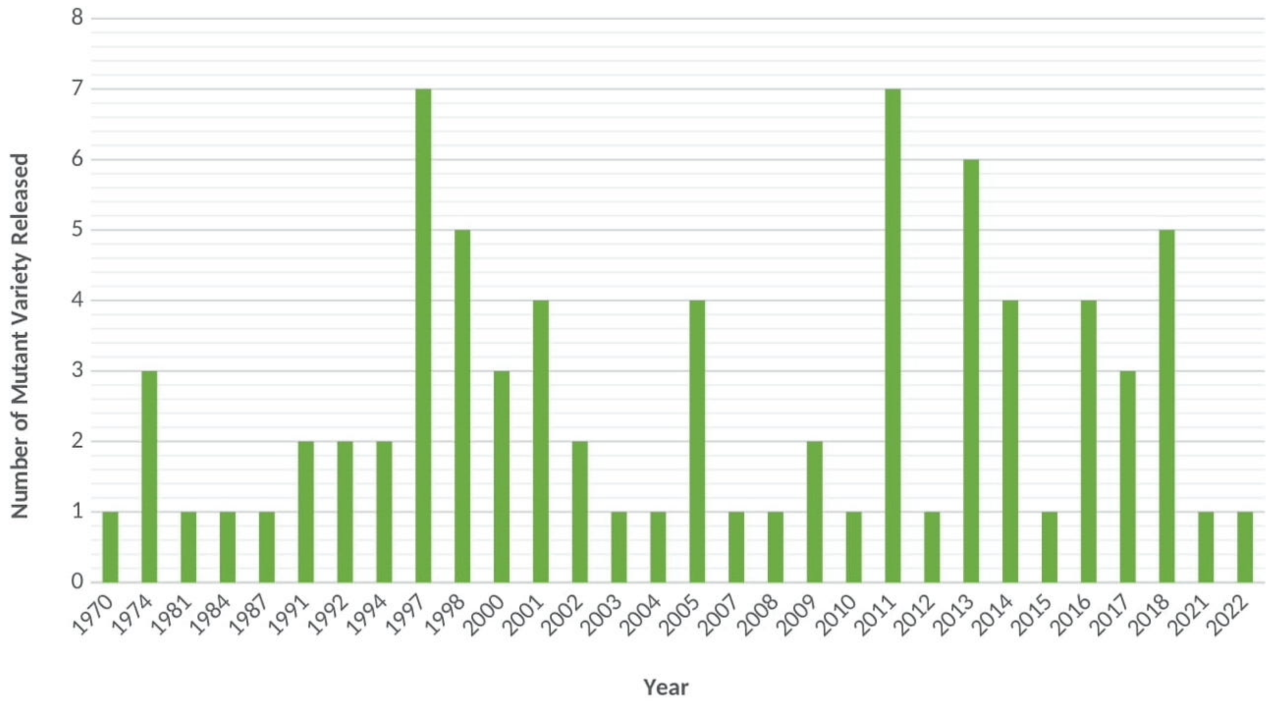


Figure 2. Trend of mutant variety release in Bangladesh. Source: Calculated from FAO/IAEE Mutant Varieties Database (MVD) (IAEA, 2022)

Binamash-1 helps farmers mitigate the risks associated with crop diseases and pests, making it a valuable addition to their production.

5.2 Improving traits in chickpeas

Yield, quality, and maturity are all important factors to consider when developing a new variety of chickpeas. One method to increase the production of high-quality chickpea seeds is through mutation breeding. This process involves introducing genetic mutations directly or by crossing with other mutant varieties to produce variations in the seed. Numerous chickpea varieties have been improved through mutation breeding, such as Binachola-4, Binachola-5, Binachola-6, Binachola-7, Binachola-8, Binachola-9, Binachoola-10, and Hypochola. These varieties not only increase yield but also improve other quality traits such as medium and large seed sizes, straw and cream-colored seed coats, and deep green leaves. Additionally, some varieties like Hyprosola and Binasola-3 exhibit early maturity to avoid adverse weather conditions.

5.3 Improving traits in grass pea

Mutagenesis is used to enhance Grass peas in a diverse range of ways. Binakhesari-1 is a high-yielding cultivar with enhanced quality features, such as reduced BOAA level and black dots on the seed coat. For every grass pea variety, having biotic and abiotic resistance characteristics is a crucial desirable attribute. Binakhesari-1, on the other hand, has significant salt tolerance and can adapt to severe drought conditions (IAEA, 2022). It was also shown to be resistant to severe diseases of legume crops like powdery and downy mildew.

5.4 Improving traits in groundnuts

Improving the yield, quality, maturity, and resistance to diseases and insects are crucial factors in developing better varieties of groundnuts. In Bangladesh, several varieties have been released through mutation breeding, resulting in higher production. BINA Chinabadam-1, BINA Chinabadam-2, BINA Chinabadam-3, BINA Chinabadam-5, BINA Chinabadam-6, BINA Chinabadam-7, BINA Chinabadam-9, and BINA Chinabadam-10 are high yielding varieties. Among them, BINA Chinabadam-5, BINA Chinabadam-6, BINA Chinabadam-7, BINA Chinabadam-9, and BINA Chinabadam-10 are commonly grown for commercial purposes. Quality is also a significant trait for groundnut cultivars. BINA Chinabadam-1 has improved attributes such as waxy leaves, larger pods and seeds, and brighter seed coat color. BINA Chinabadam-2, BINA Chinabadam-3, BINA Chinabadam-5, and BINA Chinabadam-6 have dark green, oval leaf pods, while BINA Chinabadam-4 has long, elliptical, pale green leaflets and medium-bold pods. BINA Chinabadam-9 has medium-sized pods and kernels with a dark red seed coat, while

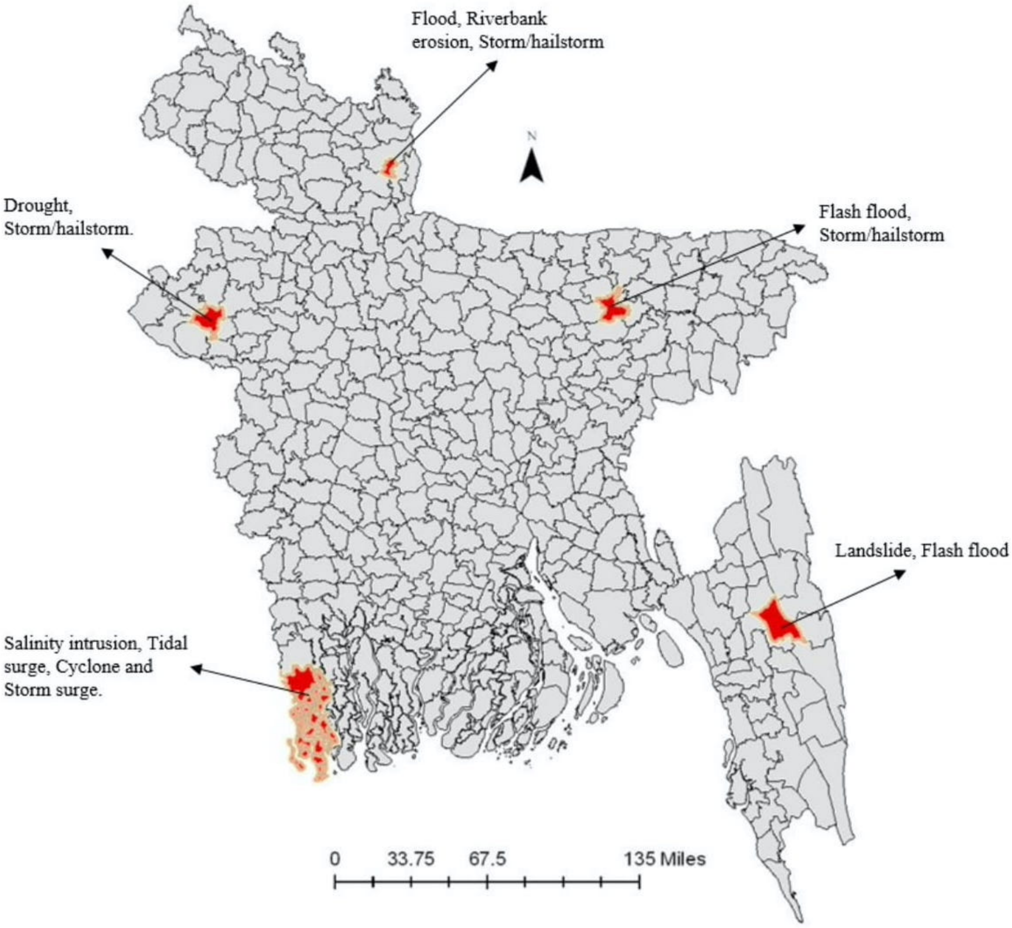


Figure 3. The current climatic hazards in various ecosystems of Bangladesh. Source: Qualitative data derived from Rahaman et al. (2018)

BINA Chinabadam-10 has a higher number of pods. BINA Chinabadam-4 is unique in its ability to mature earlier than other varieties. All the mutant groundnut varieties have higher oil and protein content, and some have shown resistance to biotic stress such as insects and diseases (Azad et al., 2014). BINA Chinabadam-1 to BINA Chinabadam-6 have moderate resistance to collar rot, Cercospora leaf spot, and rust disease, while BINA Chinabadam-7 and BINA Chinabadam-9 can tolerate jassid and hairy caterpillars. BINA Chinabadam-5, BINA Chinabadam-6, BINA Chinabadam-7, and BINA Chinabadam-9 can survive under salt stress conditions and grow in both saline and non-saline areas of Bangladesh Hossain et al. (2022); Mohammad et al. (2018).

5.5 Improving traits in Indian mustard

New varieties of Indian mustard were developed using mutation breeding to enhance their yield, resistance to diseases and insects, and seed size. Binasarisha-7 and Binasarisha-8 were created to produce high yields and resist alternaria blight and aphids, respectively. The mutation breeding technique was also used to develop Barisarisha-7, which has a bold seed size and a larger quantity of silique. Insects and diseases pose significant challenges to mustard production, but these new varieties offer improved resistance and performance.

5.6 Improving traits in jute

Jute is a crucial crop in Bangladesh. Scientists developed the Binadesipat-2 variety and other varieties with high fiber yields, early sowing potential, and white fiber through mutation breeding.

5.7 Improving traits in lentil

In Bangladesh, mutation breeding has contributed to the development of superior lentil cultivars with higher yields. Popular varieties in the country include Binamasur-1, 2, 3, 5, 6, 8, 9, 11, and 12. Quality is a crucial factor in boosting the economic value of crops. For example, Binamasur-5 is rich in protein, which is essential for human health. Binamasur-1 has reddish-yellow grains and a black seed coat, while Binamasur-11 has upright, taller plants with many

Table 2. Achievement of climate resilient traits in mutant varieties through mutagenesis in Bangladesh

Common name	Variety	IY	IQ	SM	EM	LM	IPH	RPH	DT	IT	ST	DrT	LT	FT
Black gram	Binamash-1	Yes	–	Yes	Yes	–	–	–	Yes	–	–	–	–	–
Chickpea	Binasola-10	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-2	–	–	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-3	–	Yes	–	yes	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-4	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-5	yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-6	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-7	Yes	yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-8	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Binasola-9	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Chickpea	Hyprosola	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Grass pea	Binakhesari-1	Yes	Yes	–	–	–	–	–	Yes	–	Yes	Yes	–	–
Groundnut	BINA Chinabadam-1	Yes	–	–	–	–	–	–	Yes	–	–	–	–	–
Groundnut	BINA Chinabadam-10	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Groundnut	BINA Chinabadam-2	Yes	Yes	–	–	–	–	–	Yes	–	–	–	–	–
Groundnut	BINA Chinabadam-3	Yes	Yes	–	–	–	–	–	Yes	–	–	–	–	–
Groundnut	BINA Chinabadam-4	Yes	Yes	–	yes	–	–	–	Yes	–	–	–	–	–
Groundnut	BINA Chinabadam-5	Yes	Yes	–	–	–	–	–	Yes	–	Yes	–	–	–
Groundnut	BINA Chinabadam-6	Yes	Yes	–	–	–	–	–	Yes	–	Yes	–	–	–
Groundnut	BINA Chinabadam-7	Yes	Yes	–	–	–	–	–	–	Yes	Yes	–	–	–
Groundnut	BINA Chinabadam-9	Yes	Yes	–	–	–	–	–	–	Yes	Yes	–	–	–
Indian mustard	Binasarisha-7	Yes	Yes	–	–	–	–	–	Yes	Yes	–	–	–	–
Indian mustard	Binasarisha-8	Yes	–	–	–	–	–	–	Yes	Yes	–	–	–	–
Jute	Binadeshipat-2	–	yes	–	Yes	–	–	–	–	–	–	–	–	–
Lentil	Binamasur-1	Yes	–	–	–	–	–	–	Yes	–	–	–	–	–
Lentil	Binamasur-11	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Lentil	Binamasur-12	Yes	–	–	–	–	Yes	–	–	–	–	–	–	–
Lentil	Binamasur-2	Yes	–	–	Yes	–	–	–	Yes	–	–	–	–	–
Lentil	Binamasur-3	Yes	–	–	Yes	–	–	–	Yes	–	–	–	–	–
Lentil	Binamasur-5	Yes	Yes	–	Yes	–	–	–	Yes	–	–	–	–	–
Lentil	Binamasur-6	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Lentil	Binamasur-8	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Lentil	Binamasur-9	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Mungbean	Binamoog-1	Yes	–	–	–	Yes	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-2	Yes	Yes	Yes	Yes	–	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-3	Yes	–	Yes	–	Yes	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-4	Yes	Yes	Yes	Yes	–	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-5	Yes	–	Yes	–	–	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-6	Yes	–	–	Yes	–	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-7	Yes	–	Yes	Yes	–	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-8	Yes	Yes	–	Yes	–	–	–	Yes	–	–	–	–	–
Mungbean	Binamoog-9	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Onion	Binapiaz-1	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Onion	Binapiaz-2	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Oriental mustard	Agrani	Yes	Yes	–	Yes	–	–	–	Yes	–	–	–	–	–
Oriental mustard	Safal	Yes	Yes	–	–	–	Yes	–	Yes	Yes	–	–	–	–
Oriental mustard	Shambal(BAU-M/248)	–	Yes	–	–	–	–	Yes	–	–	–	–	–	–
Rape seed	Binasarisha-5	Yes	Yes	–	–	–	–	–	Yes	–	Yes	–	–	–
Rape seed	Binasarisha-6	Yes	Yes	–	–	–	–	–	Yes	–	Yes	–	–	–
Rape seed	Binasarisha-9	Yes	Yes	–	–	–	–	Yes	Yes	Yes	–	–	–	–
Rape seed	Binasharisha-3	Yes	Yes	–	Yes	–	–	–	Yes	–	–	–	–	–
Rape seed	Binasharisha-4	Yes	Yes	–	Yes	–	–	–	Yes	–	–	–	–	–
Rice	Binadhan-13	Yes	Yes	–	–	–	–	–	–	–	–	–	Yes	–
Rice	Binadhan-14	–	–	–	Yes	–	–	Yes	–	–	–	Yes	–	–
Rice	Binadhan-18	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Rice	Binadhan-19	Yes	–	–	Yes	–	–	Yes	–	–	–	–	–	–
Rice	Binadhan-20	Yes	Yes	–	Yes	–	–	–	–	–	–	–	–	–
Rice	Binadhan-25	Yes	Yes	–	Yes	–	Yes	–	–	–	–	–	–	–
Rice	Binadhan-4	Yes	Yes	–	Yes	–	Yes	–	Yes	Yes	–	–	Yes	–
Rice	Binadhan-5	Yes	Yes	–	Yes	–	–	–	–	–	–	–	Yes	–
Rice	Binadhan-6	Yes	–	–	–	Yes	Yes	–	–	–	–	–	–	–
Rice	Binadhan-7	Yes	Yes	–	Yes	–	–	Yes	Yes	Yes	–	–	–	–
Rice	Binadhan-9	–	–	–	Yes	–	–	–	–	–	–	–	Yes	–
Rice	Binasail	Yes	Yes	–	Yes	–	–	–	–	–	–	–	–	–
Rice	Iratom 24	Yes	Yes	–	Yes	–	–	Yes	Yes	Yes	–	–	Yes	–
Sesame	Binatil-1	–	Yes	–	–	–	–	–	Yes	–	–	–	–	–
Sesame	Binatil-2	Yes	Yes	–	–	–	–	–	–	–	–	–	–	Yes
Sesame	Binatil-3	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Sesame	Binatil-4	Yes	Yes	–	–	–	–	–	–	–	–	–	–	Yes
Tomato	Bahar	Yes	Yes	–	–	–	–	–	–	–	–	–	–	–
Tomato	Binatomato-13	Yes	–	–	–	–	–	–	–	–	–	–	–	–
Tomato	Binatomato-2 (N/A)	–	–	–	–	–	–	–	–	–	–	–	–	–
Tomato	Binatomato-3 (N/A)	–	–	–	–	–	–	–	–	–	–	–	–	–
Tossa jute	Atompat-28	Yes	Yes	–	–	Yes	–	–	–	–	–	–	–	–
Tossa jute	Atompat-36	Yes	Yes	–	–	Yes	–	–	Yes	–	–	–	–	–
Tossa jute	Atompat-38	Yes	Yes	–	–	–	Yes	–	–	–	–	–	Yes	–
Tossa jute	Binapatshak-1	Yes	–	–	Yes	–	–	–	–	–	–	–	–	–
Wheat	Binagom-1	Yes	–	–	–	–	–	–	–	–	Yes	–	–	–

Source: FAO/IAEA Mutant Varieties Database (MVD) (IAEA, 2022) branches and green and violet blooms. Binamasur-12 is characterized by its white stem, dark green foliage, and pink flowers. These cultivars not only offer better yields but also enhanced plant height. Maturity is also an essential consideration in developing lentil varieties. Mutation breeding has resulted in several short-lived cultivars that can withstand unfavorable climatic conditions. Binamasur-2, 3, 5, 6, 8, 9, and 11 are early maturing varieties. Additionally, only a few lentil varieties are resistant to major pests and diseases. Four mutant varieties, Binamasur-1, 2, 3, and 5, are resistant to rust and blight diseases.

5.8 Improving traits in mung bean

To increase production and value, mung bean cultivars must meet specific quality standards. Many of these varieties were developed through mutation breeding and are known for their high yields. These quality traits include larger seed size (Binamoog-2), deep green leaves, attractive green seed coat, and superior protein quality (Binamoog-8). A key quality for mung bean to cope with climate change is maturity, which can be achieved through early, late, or synchronous maturation to avoid severe weather events. Mutation breeding has contributed to the development of both early-maturing (Binamoog-2, Binamoog-4, Binamoog-6, Binamoog-7, Binamoog-8, and Binamoog-9) and late-maturing (Binamoog-1 and Binamoog-3) varieties. Additionally, many mung bean varieties (such as Binamoog-2, Binamoog-3, Binamoog-4, Binamoog-5, and Binamoog-7) have synchronous pod maturation. Disease and insect infestations pose a significant threat to mungbean cultivars. However, Binamoog-1, Binamoog-2, Binamoog-3, Binamoog-4, Binamoog-5, Binamoog-6, Binamoog-7, and Binamoog-8 mutants have been proven to be resistant to yellow mosaic virus (YMV) and Cercospora leaf spot (Ahmed et al., 2022; IAEA, 2022). Of all the mung bean varieties, only Binamoog-4 is a dwarf-type plant, making it relatively rare.

5.9 Improving traits in onion

To increase seed and bulb production in Bangladesh, it is important to focus on genetic traits that promote high yield and quality. The Binapiaz-1 and Binapiaz-2 mutant types are excellent options as they can produce high yields of seeds in the winter and dry bulbs in the summer. Additionally, Binapiaz-2 is particularly effective at generating seeds in the winter months. Another crucial factor to consider when aiming for global supply is quality. Binapiaz-1 produces fresh and dry bulbs, while Binapiaz-2 has a longer shelf life.

5.10 Improving traits in oriental mustard

Through the process of mutagenesis, various important traits have been developed in mustard plants such as high yield, quality, maturation time, plant height, and resistance to disease and insects. Quality traits like large-seeded (Shambal), strong and erect plant (Safal), and higher oil content (Agrani, Safal) have been achieved through mutation breeding. Additionally, high-yielding varieties (Safal, Agrani), short plant-height varieties (Shambal), and tall plant-height varieties (Safal) have also been successfully developed through mutation breeding. Maturity is a crucial characteristic for plants to adapt to various cropping patterns, and early mature varieties (Agrani) have been created through mutation breeding, which is suitable for fallow land from December to May (Rahman and Das, 1994). Disease and insects pose a significant threat to mustard production, and to combat this, alternaria disease and insect aphid tolerant varieties, Safal and Agrani, have been developed through mutation breeding.

5.11 Improving traits in rapeseed

Many desirable traits in rapeseed, such as high yield, salt tolerance, resistance to disease and insects, seed coat color, shorter height, low erucic acid content, and early maturity, have been developed through mutation breeding. Yield is a major factor in improving rapeseed, and high-yielding varieties like Binasarisha-3 and Binasarisha-4 were developed through mutation breeding. Salty soils are common in some parts of our country, and mutation breeding has played an important role in developing salt-resistant varieties like Binasarisha-5 and Binasarsiha-6. Diseases and insects can significantly reduce agricultural output, but mutation breeding has helped discover Alternaria-resistant (Binasarisha-9) and stem root-resistant (Binasarisha-9) varieties. Erucic acid is a typical constituent of mustard but the presence of excessive erucic acid may lead to adverse health effects (Wendlinger et al., 2014). The mutant rapeseed variety. Binasarisha-3, Binasarisha-4, Binasarisha-5 have significantly low levels of erucic acid and high levels of oleic, linoleic and linolenic acids (Mortuza et al., 2006). These mutant varieties also come in quality seed coat colors, such as pale yellow (Binasarisha-6), reddish brown (Binasarisha-5), and black (Binasarisha-9).

5.12 Improving traits in rice

When selecting crop varieties, important factors to consider include yield, quality, and resistance to biotic and abiotic stressors. In mutant rice varieties, improvements have been made in these areas, particularly in terms of grain quality. Various mutations have led to the production of longer, finer grains with good cooking quality and high market value, as well as bold, brightly colored grains. Mutations have also contributed to the development of both early-maturing and late-maturing rice varieties, which can better adapt to changing climates by avoiding extreme weather events. Additionally, plant height and lodging are important factors to consider, as very tall or very short plants can negatively impact production. Through mutation breeding, desirable plant height and lodging-resistant varieties have been produced. Finally, mutant rice varieties have shown tolerance or resistance to major insect and disease threats, as well as drought (Azad et al., 2012; Rahman et al., 2012; Haque et al., 2019; Viana et al., 2019; Rahman et al., 2020).

5.13 Improving traits in sesame

In the same species, a variety of traits were developed through mutation breeding, such as stem rot resistance, high seed production, branching plants, and waterlogging tolerance. Stem rot is a major concern for growing sesame, but with mutagenesis, varieties like Binatil-1, Binatil-2, Binatil-3, and Binatil-4 were created to resist it. In Bangladesh, it is common to have flooding due to excessive rain. However, through mutation breeding, the waterlogging-tolerant Binatil-24 variety was obtained. For plants to produce more, they need a branching architecture, and mutagenesis helped create the branched architectural plants Binatil-2 and Binatil-3. Mutation breeding also played a significant role in producing high-yielding varieties like Binatil-1, Binatil-3, and Binatil-4. Additionally, the high oil content variety Binatil-1 was developed through mutation.

5.14 Improving traits in tomato

Tomatoes are a popular crop in Bangladesh, and they have been improved through mutation breeding. This process has led to the development of desirable traits such as determinate growth, high yield, improved quality, and specific height varieties. The mutation breeding has resulted in the creation of two new tomato varieties: Bahar and Binatomato-13. Bahar is known for its high fruit yield and quality, while Binatomato-13 has a desirable height of 120-130 cm and produces red fruit.

5.15 Improving traits in tossa jute

Mutation breeding in tossa jute led to the development of several traits, including fiber, fiber quality, yield, maturity, lodging, and stiff stem. Through mutagenesis, high-yielding variety (atompat-36, 38) and increased fiber yield variety (Atompat-24, Atompat-36, Atompat-38) were developed. The mutation also resulted in the creation of high-quality fiber varieties (Atompat-38), late-blooming varieties (Atompat-28), and late-maturing varieties (Atompat-36). Moreover, strains with stem rot resistance (Atompat-36) and lodging resistance (Atompat-38) were developed (Shamsuzzaman et al., 2005). Additionally, a unique genetic marker was identified in Atompat-38, which aids in seed quality. It is worth noting that storms do not lodge the stiff stem, which is present in Atompat-38 (IAEA, 2022).

5.16 Improving traits in wheat

Salt-tolerant mutant wheat variety namely Binagom-1 is a breakthrough (Mohammad et al., 2018). Its development of salt-tolerant characteristics makes it ideal for wheat cultivation in the coastal regions of Bangladesh, where salinity is a major concern.

6 The impact of mutant varieties in Bangladesh

Different mutant varieties have adapted to various ecosystems in the country, which is essential for socio-economic sustainability. Cultivating these mutant varieties benefits farmers as it increases their acceptance and promotes their spread across different regions. The coastal region of Bangladesh is facing salinity issues due to rising sea levels. Haque et al. (2019) conducted a study that found Binadhan-8 and Binadhan-10 varieties are suitable for farming in coastal areas like Bagerhat, Cox's Bazar, Chattogram, Khulna, Patuakhali, and Sathkhira. Farmers can benefit from cultivating these varieties as they are profitable. Other mutant rice varieties like Binadhan-7 are being grown in different parts of the country, including Barishal, Bogura, Chattogram, Cumilla, Dhaka, Dinajpur, Faridpur, Jashore, Khulna, Moimonsingho, Rajshahi, Rangamati, Rangpur, and Sylhet. Binadhan-7 has gained popularity among farmers for its adaptability to various cropping systems, raising cropping intensity in a particular region (Rahman et al., 2020). Rice (Binadhan-7)-Chickpea (Binasola-4)-Mungbean (Binamoog-5) is an efficient cropping pattern for mutant varieties (Sarkar et al., 2013), and growing Binadhan-7 has many benefits for farmers, including boosting capital (Rahman et al., 2021), economic (Rahman et al., 2012, 2021), resolving the monga problem (Rahman et al., 2021), enhancing quality of life (Sarkar et al., 2013), and assuring food security (Sarkar et al., 2013; Rahman et al., 2020). The Binamoog-8 mutant mungbean variety with synchronized maturity traits has made harvesting easier and improved resource utilization on char land, according to Islam and Miah (2014). Additionally, sesame and mustard crops are profitable for farmers in various regions. Farmers in Magura, Kushtia, Jhenaidah, Madaripur, and Faridpur have found Binatil-3 to be profitable (Islam et al., 2021), while

Binasarisha-4 is considered beneficial by most farmers in Jashore, Kushtia, Magura, and Faridpur (Sarkar et al., 2020). However, novel mutant varieties are being grown whose benefits to the climate and economy have not yet been researched. Therefore, there is a need to conduct studies on the effects of mutant varieties on various aspects, including social, economic, climatic, nutritional, and food security.

7 Conclusion

Bangladesh is a densely populated agricultural country that is currently facing vulnerability due to climate change. To ensure food security amidst increasing climatic events, crops with climate-resilient traits are necessary. Crop improvement in Bangladesh is ongoing through mutation breeding, where mutant varieties with climate-resilient traits are being developed. Plant breeders are working hard to develop numerous mutant varieties to maintain fundamental food security and fulfill human needs. Mutagenesis contributes significantly by creating genetic variation within a short time, providing nutritional, abiotic, and biotic resistant traits, and yield and yield contributing traits. Many mutant varieties with climate-resistant traits have been invented for Bangladesh, contributing to climatic adaptation for sustaining agricultural production. However, these varieties may not be sustainable for a long time due to changing climate. Development of varieties required a long time which is a considerable barrier to developing climate-resilient varieties in this era. As continuous climate scenarios increase the necessity of trait improvement, plant breeders must work on specific climate-resilient traits, such as drought, saline, and flood-prone areas, to promote their genetic availability. In the long run, plant breeders must integrate modern tools in mutation breeding to work together for adapting multiple crops in different ecological zones in Bangladesh. Our review describes the contribution of mutagenesis to varietal development concerning climate change and provides a valuable pathway for breeders to decide future actions about adaptation options in the context of Bangladesh.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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