Nuclear Agriculture: Crop Mutant Varieties and Related Agri-Technologies for Societal Benefits

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Preamble

India is an agrarian country, whose economic development is vastly dependent on sustained growth and achievements in agriculture sector amid raising population, shrinking arable land and adverse effects of climate change. Current and future challenges in Indian agriculture need to be addressed through innovative agricultural research along with appropriate policies, effective delivery and market systems. Synergistic blend of conventional and advanced methodologies in crop improvement, crop production and crop protection would holistically contribute to agricultural research for achieving national food and nutritional security. Crop improvement through mutation breeding, among various breeding methodologies, has played an important role in inducing novel genetic variability, improving existing popular variety and developing promising varieties in different crop plants. BARC has been engaged in mutation breeding since fifties using ionizing radiations like x-rays, beta particles, gamma rays and electron beam. Using radiation-based mutants and their derivatives in crosses; BARC has developed 55 varieties with improved traits in different crops in collaboration with State Agricultural Universities and ICAR research institutes. These varieties have been released for farmer cultivation across India. Several of BARC varieties have been cultivated extensively by farmers from different states and have immensely benefitted them by enhancing their farm income.

1. Introduction

The agriculture sector is an important sector for India's economic development for alleviating poverty and ensuring food and nutritional security. Current and future challenges in Indian agriculture need to be addressed through synergistic blend of conventional and advanced methodologies in crop improvement, crop production and crop protection for achieving national food and nutritional security.

Crop improvement is a continuous process for evolution of promising and improved varieties for which, a basic necessity is to ensure greater genetic variability for target traits. In nature, new variability is generated by spontaneous genetic changes (mutations) due to effect of natural radiations and other factors, which occur at extremely low frequency (one in a million). Using atomic radiations and/or other chemical mutagens, mutation frequency can be enhanced to several folds (one in thousands). Development of such mutants (induced mutagenesis) has been successfully employed for improvement of most of the crops (mutation breeding). Bhabha Atomic Research Centre (BARC) has been contributing in the field of agriculture by using radiations to develop newer crop varieties through mutation breeding; to control insect pests; to trace the pesticide residues and uptake of fertilizers and other nutrients.

The phenomenon of induced mutagenesis for crop improvement dates back to early 20th century with the occurrence of changes in barley seedlings and sterility in maize tassels after X-ray irradiation as shown by Stadler in 1928. In line with the national breeding programs towards enhancing production of cereals, oilseed and pulse crops, BARC has been undertaking genetic enhancement of these crops through radiation induced mutagenesis. Way back in 1957, experiments were initiated in over 50 varieties of several crop plantst o understand the effect of radiations like x-rays, neutrons and gamma rays by studying radiosensitivity, mutation frequency, cytological aberrations, morphological, biochemical and physiological traits [1-4].

2. Protocols in Mutation Breeding

In mutation breeding, the main goal is to develop suitable varieties with enhanced seed yield and nutrients, earliness, desired seed size and dormancy, tolerance to diseases, insects, drought, salinity, heat, etc. Seeds of existing popular cultivars, varieties, mutants, selections, hybrids or advanced lines of target crop are treated with different radiations (Mutagen) like, x-rays, beta rays, gamma rays, fast neutrons, electron beam (M_1 generation). The effective dose ideal for mutant induction was close to Ld_{50} (50% lethal dose) depending on radio-sensitivity factors. These treated seeds of different crops are sown in the agricultural fields. Usually genetic variants (mutants) are identified from next generation (M_2) onwards. In the subsequent generations, breeding behavior of the induced mutants is studied and is followed till the induced mutant becomes genetically stable (attaining homozygosity). Indian Council of Agricultural Research (ICAR) through their coordinating units and the State Agriculture Universities (SAUs) evaluate these stabilized mutants with the existing varieties over the locations and seasons to find their suitability and adaptability. Based on the superiority of new mutant, varietal identification committee of ICAR/SAU recommends the suitable mutant for release. Further, Department of Agriculture and Cooperation, Ministry of Agriculture & Farmers Welfare, Government of India releases and notifies new mutant for commercial cultivation [6]. Sometimes, such mutants are crossed with other mutant or variety to integrate the beneficial traits from both the parents (Recombination or cross breeding). BARC/SAUs undertake breeder seed production of new mutant varieties followed by foundation and certified seed production by the national and state seed corporations, seed companies and other seed agencies to reach the farmers with the seeds of new mutant variety.

3. Development of Trombay Mutant or Mutant Derived Varieties

Using radiation induced mutagenesis, hundreds of mutants with various desirable traits were developed in different crop plants at BARC. Such mutants were directly utilized or judiciously blended to develop 55 varieties, which have been released and Gazette notified for commercial cultivation across the country during 1973-2022 period. These include 16 varieties in groundnut; 8 in mungbean; 7 each in mustard and rice; 5 each in urdbean and pigeonpea; 2 each in cowpea and soybean and one each in linseed, sunflower and jute. These Trombay varieties have extensive public acceptance and are being widely cultivated. Synergistic research collaborations and memoranda of understandings (MoUs) between BARC and ICAR institutes and SAUs have enabled successful development and dissemination of Trombay varieties wide across the country.

3.1 Oilseed crops

3.1.1Groundnut

Groundnut mutation studies were started with X-ray irradiation in 1957 at BARC, followed by gamma rays and electron beam. Initially, mutant gene pool having many divergent mutants was created with repeated mutational events. Consistent breeding efforts using these mutants in recombination breeding has developed and released 16 Trombay groundnut (TG) varieties for cultivation in different states. The first BARC variety was TG 1 with large seed developed in 1973 by X-ray irradiation. With this, saga of release of mutant variety was continued at BARC with one more X-ray mutant variety, TG 3. Inter-mutant crosses resulted in the development of TG 17 variety. Crosses involving both TG 1and TG 17 was carried out to develop a large seed variety, TKG 19A. Further, these TG mutants and their derivatives were genetically diversified by other varieties to develop TGS-1 (Somnath) and TG 22. Multiple crosses involving these mutants and M 13 has resulted in the development of four varieties, TAG 24, TG 39, TLG 45 and RARST-1 (TG 47). Genetic diversification of these mutants was sustained by involving more parents for incorporation of newer characters, which has evolved five varieties, TG 26,TG 37A, TG 38, TPG 41 and TG 51 for different states [6]. Recently, a gamma ray mutant, TAG 73 has been released for Maharashtra. In state groundnut breeding programmes, TG varieties were used as parents in the development and release of another 14 varieties by different agricultural universities in Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan and Telangana.

Various characters like compact plant type, large seed, early maturity, fresh seed dormancy, drought tolerance, high oleic acid found in TG varieties were advantageous for different cropping systems and situations. Based on the indent and demand from various seed agencies, around 700 tonnes breeder seeds of TG varieties were produced and supplied by BARC for further foundation and certified seed production in several states including Gujarat, Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal. Most of these TG varieties have considerably benefited thousands of farmers, traders and exporters. Photograph of actual seed multiplication of groundnut variety (TG 39) on farmer's field in Maharashtra is depicted in Fig 1. Produce from this field is used as seed for sowing purpose in the next season by the farmers.

Fig. 1: Breeder seed multiplication field of groundnut variety TG 39 in Maharashtra

3.1.2 Mustard

Mutation breeding in Indian mustard at BARC has generated a wide spectrum of mutations for morphological, physiological, biochemical, yield and yield contributing characters. Sustained breeding efforts involving these mutations have evolved seven mustard varieties, which are released in different states. In mustard, yellow seed coat mutant has more oil, more protein, thinner seed coat and lower fiber compared to brown seed coat parents. First yellow seed coat mutant in India, Trombay Mustard 1 (TM1) was developed by BARC from variety Rai 5 using beta rays from Phosphorus-32 (^{32}P) radioisotope. Recurrent selection in the same mutant has resulted in high yielding variety, TPM 1 (Fig. 2). TPM 1 has reduced erucic acid up to 25% compared to 47% in traditional rapeseed-mustard oil. Earlier years, a direct mutant TM2 and a mutant derivative TM4 have been released. TM4 and TPM1 are yellow seed coat varieties. Recently, another yellow seed variety TBM204 has been released for West Bengal. In 2022, three more varieties have been released: Trombay Him Palam Mustard 1 (THPM-1) for Himachal Pradesh; Birsa Bhabha Mustard-1 (BBM-1) for Jharkhand and TAM 108-1 for Maharashtra.

Fig. 2: Trombay mustard variety, TPM-1

3.1.3 Other oilseed crops

In soybean, radiation induced mutagenesis has generated diverse genetic variability both for quantitative and qualitative traits. BARC has developed two soybean varieties viz., TAMS 38, a gamma ray mutant of JS 80-21 and TAMS 98-21, a cross derivative with superior seed yield, non-pod shattering, resistance to diseases and pests. Both the varieties were cultivated widely by the farmers in Vidarbha region of Maharashtra. Linseed oil contains mainly unsaturated fatty acids like oleic acid (16–24 %), linoleic acid (18–24 %) and linolenic acid (36–50 %). Its oil is unfit for edible purpose as it develops off-flavours during storage due to its oxidation. Varieties with low linolenic acid will enable linseed oil to use as edible oil. BARC has developed yielding variety, TL 99 with 2-5% linolenic acid which was released for commercial cultivation in 2019. TL 99 is the first Indian variety released for edible oil. In sunflower, gamma ray mutagenesis of zebra stripped seed coat variety Surya has resulted in high yielding black seed coat variety, TAS 82, which was released for cultivation in Maharashtra.

3.2 Pulse crops

Pulses are the vital component for dietary proteins in carbohydrate rich staple food for our sizable vegetarian population. BARC has been actively engaged in the genetic improvement of pulse crops namely, blackgram/urdbean, greengram/mungbean, pigeonpea, cowpea and recently in chickpea and cluster bean through mutation and recombination breeding. Gamma rays have been found to be the most potent among different mutagens. BARC has developed 20 varieties in pulses which include eight in mungbean, five each in urdbean and pigeonpea and two in cowpea [7]. Most of these Trombay pulse varieties are mutant derivatives developed by mutant-genotype or inter-mutant (TAT-10 in pigeonpea) hybridizations, while some varieties (TAP-7 in mungbean, TT-6 in pigeonpea and TRC77-4, TC-901 in cowpea) are direct mutants. In urdbean, large seed mutants, UM-196 (dark green leaf mutant) and UM-201 were hybridized with popular cultivar T-9 resulting in three improved varieties, TAU-1, TAU-2 and TPU-4. Similarly, in pigeonpea, a fast neutron induced large seed mutant variety TT-6 was hybridized with ICPL 84008 and three high yielding varieties (TT-401, TJT-501 and PKV-TARA) with early maturing period have been developed. In mungbean, crosses involving Kopergaon and TARM-2 have resulted in the development of TMB-37 variety with early maturity characteristics. Some of the mutant varieties like TM-96-2, TM-2000-2 (mungbean), TU-40 (urdbean) and TRC-77-4 (cowpea) are also suitable for rice fallows. Cowpea variety, TC-901 is the first summer suitable variety in the country.

Many of the Trombay pulse varieties are popular among the farmers owing to their superior yield and disease resistance attributes. Near about 155 tonnes of breeder seeds have been produced and distributed to the farmers during the last five years. The urdbean mutant TAU-1 is the most successful variety occupying more than 50% of the urdbean area in Maharashtra. The recently released urdbean variety TU-40 associated with high yield has become popular in the southern states. The mungbean variety, TMB-37 though initially released for North-East plain zone, is gaining popularity across the country and has been re-adopted in 2018 by Punjab owing to its large seed, yellow mosaic virus resistance and suitability for summer cultivation. The early maturing pigeonpea variety, TJT-501 occupies almost 60% of the area under pigeonpea in Madhya Pradesh (Fig. 3). The farmers of Maharashtra are reaping high yields by cultivating pigeonpea variety PKV-TARA especially under drip irrigation [8].

Fig. 3: Trombay pigeonpea variety, TJT-501

3.3 Rice

Radiation induced mutagenesis has been successfully employed at BARC for rice improvement resulting in the release of seven varieties. Among these, Trombay Chhattisgarh Dubraj Mutant-1 (TCDM-1), Vikram-TCR, CG Jawaphool Trombay, Trombay Chhattisgarh Vishnubhog Mutant (TCVM) and Trombay Chhattisgarh Sonagathi Mutant (TCSM) all being gamma ray mutants, have been released for commercial cultivation in Chhattisgarh, while a mutant derivative, Trombay Karjat Kolam Rice (TKR Kolam) has been released for Maharashtra. TCDM 1 has retained the aroma and grain quality of parent variety, Dubraj. TKR Kolam has superfine grain and better taste. Vikram-TCR is high yielding, dwarf, non-shattering and non-lodging, mid-early maturity with long slender grain, drought tolerance and better puffed rice making quality. CG Jawaphool Trombay is high yielding, semi-tall, non-shattering and non-lodging with aromatic short grains and better Kheer making quality. These rice varieties have been developed in collaboration with Indira Gandhi Krishi Vishwavidalaya (IGKV), Raipur, Chhattisgarh and Dr. D.B. Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra.

4. Dissemination of Trombay Mutant Varieties

BARC has followed multi-pronged approaches to disseminate Trombay varieties wide across the country. It has participated in exhibitions, Kisan Melas and conducted field demonstrations under the Public Awareness Programme on Peaceful Uses of Atomic Energy in order to create awareness about the Trombay varieties. As per the national indent from various seed agencies and seed growers, nearly 1000 tonnes of breeder seed of Trombay varieties were multiplied and supplied to National Seed Corporation, State Seed Corporations of Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Maharashtra, Odisha, Rajasthan and West Bengal; National Institutes; State Agricultural Universities; State Agricultural Departments; Seed companies; Non-Governmental Organizations and farmers. Apart from this, different State Agricultural Universities also distributed hundreds of tonnes breeder seeds of BARC crop varieties. Such variety of the seed was further multiplied, distributed and spread horizontally to thousands of hectares and widely accepted by the farming community in turn contributing significantly towards food and nutritional security of the country (Fig. 4).

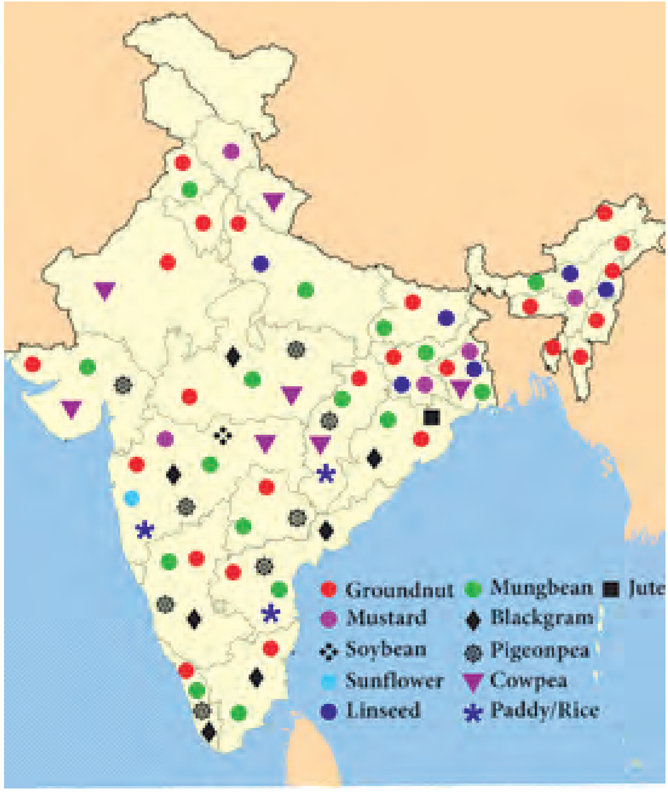

Fig. 4: Deployment of Trombay varieties across the country.

5. In Vitro Mutagenesis

Noteworthy research has been carried out in the areas of plant/cell tissue culture, in vitro mutagenesis, molecular stress biology, molecular markers, micropropagation, cell culture /hairy root based production of bioactive compounds, cloning of desirable genes and developing transgenic plants for stress tolerance. Transgenic banana plants have been developed for biotic and abiotic stress tolerance. In vitro mutagenesis of banana with gamma rays at BARC resulted in desirable dwarf mutants [9]. Dwarf mutant, TBM-9 has performed better in national multi-location trials. In vitro mutagenesis of sugarcane along with cellular selection for salt tolerance at BARC has identified mutants, AKTS-01 and AKTS-02 having superior total plant height, millable cane height and number.

6. Agro-based BARC Technologies

In addition to crop improvement, radiations and radioisotopes are used in agricultural research to manage insect pests, to monitor fate and persistence of pesticides, to study fertilizer use efficiency and also to preserve agricultural produce. BARC has developed various technologies for micropropagation of banana, pineapple, turmeric, ginger; bio-control formulations; for detection of insecticides; for decomposition of different types of biodegradable wastes and soil organic carbon detection kit, which have been transferred to several agencies across the country (Table 1).

Table 1: BARC agro-based technologies along with their applications

Technology	Application
Bio-fungicide formulation Tricho BARC of an improved *Trichoderma Virens* Mutant Strain	Seed treatment for bio-control of seedling diseases in crop plants
Nisargruna biogas technology	To decompose biodegradable and to provide high quality manure and methane gas. It has potential of solving the solid waste management issue in the urban areas.
Compact Helical Biodegradable Waste Converter, SHESHA	To decompose biodegradable waste and to generate good quality fuel and manure for soil applications.
A rapid composting technology for decomposition of dry leaves, kitchen waste and temple waste	Microbial decomposition of kitchen/market waste, dry plant matter (including coconut leaves), straw/agricultural residue and waste from temples
A rapid, continuous and renewable method for multiplication of *Ophiorrhiza Rugosa*	Sustainable source of anticancer drug camptothecin.
Micropropagation protocol for banana, pineapple, turmeric, ginger	Multiplication of disease free, good quality planting material throughout the year and can also be used in germplasm conservation of elite varieties.
Biopesticide formulation based on *Bacillus thuringiensis* Subsp. *Kenyae* HD-549	Control of different agriculturally important insect pests.
Biosensor kit for Organophosphate and organo-carbamate pesticides	Detection of organophosphate and organo-carbamate pesticides in food samples, which will be useful for farmers, traders and consumers
Superabsorbent BARC hydrogel (MRIDAMŔT)	Hydrogel can absorb and retain pure water up to 550 times of its own weight and supply to plant roots. It increases the soil water holding capacity.
Soil organic carbon detection kit	To help farmers to understand their field's carbon status in 15-20 minutes

7. Conclusion and Future Prospects

A judicious blend of mutation and recombination breeding has been found promising in the genetic improvement of crop plants as exemplified by crop breeding efforts undertaken at BARC, Trombay. Mutant varieties also have been used extensively as parental material in the national and state breeding programmes in respective plant species. Additionally, induced mutants are ideal resource genetic material for studying functional genomics. Crop improvement is a continuous process wherein new mutants and breeding lines in different crops including vegetatively propagated plants will be developed by employing gamma rays, proton beam, electron beam-based mutagenesis and targeted mutagenesis to accomplish the future needs of the farmers particularly under changing climatic conditions. Such breeding cycle will be hastened by adopting in vitro mutagenesis, speed breeding and marker-assisted breeding techniques.

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