Radiation Technology in Agriculture for Development of Improved Crop Varieties

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ABSTRACT

Radiations and radioisotopes are used in agricultural research to induce genetic variability in crop plants to develop improved varieties, to manage insect pests, monitor fate and persistence of pesticides, to study fertilizer use efficiency and plant micronutrient uptake and also to preserve agricultural produce. Use of radiation and radioisotopes in agriculture is one of the most important fields of peaceful applications of atomic energy for societal benefit and BARC has contributed significantly in this area especially in the development of new mutant crop varieties. With an effective blend of induced mutagenesis along with recombination breeding 42 new crop varieties developed at BARC have been released and Gazette notified by the Ministry of Agriculture, Government of India for commercial cultivation. These include 21 in oilseeds (15-groundnut, 3-mustard, 2 soybeans, 1 sunflower), 19 in pulses (8-mungbean, 5-urdbean, 5-pigeonpea, 1-cowpea) and one each in rice and jute. Some of the desirable traits which have been bred through induced mutations in these crops include higher yield, improved quality traits, early maturity and resistance to biotic and abiotic stress. Several of these varieties have high patronage from the farming community and are extensively grown across the country.

I INTRODUCTION

Indian agriculture in the past has witnessed green revolution, which has changed the nation's status from a food importing to a self sufficient nation. In spite of industrialization, India remains an agrarian economy, and over 50% of its population is employed in agriculture and related enterprises. The national agricultural policy focuses on sustained production and nutritional security for the one billion plus population. Food grain production in India stands at around 255 million tons and by 2025 we may need about 340 million tons to feed the increasing population To further increase agricultural productivity equitably in an environmentally sustainable manner in the face of diminishing land and water resources is a highly challenging task. There is a need to develop better crop varieties which are high yielding and resistant to biotic and abiotic stresses.

The Department of Atomic Energy through its research, development and deployment activities in nuclear science and technology, has been contributing towards enhancing the production of agricultural commodities and their preservation. Radiations and radioisotopes are used in agricultural research to induce genetic variability in crop plants to develop improved varieties, to manage insect pests, monitor fate and persistence of pesticides, to study fertilizer use efficiency and plant micronutrient uptake and also to preserve agricultural produce. Use of radiation and radioisotopes in agriculture which is often referred to as nuclear agriculture is one of the important fields of peaceful applications of atomic energy for societal benefit and BARC has contributed significantly in this area.

II RADIATION TECHNOLOGY IN THE DEVELOPMENT OF NEW CROP VARIETY

Traditionally, selection and hybridization have been employed in the improvement of crop varieties for enhancing agricultural productivity. Genetic variability in crop plants is a valuable resource from which the plant breeder can select and combine different desired characteristics to produce better crop varieties. Natural variability is generated by spontaneous mutations which occur at extremely low frequency (roughly 10-6). This can be enhanced to several fold (approximately 10-3) using chemical or physical mutagens. Mutations, spontaneous or induced, are an important source for inducing genetic variability. Improvement in either single or few economic traits and quality characters can be achieved with the help of induced mutations within the shortest possible time. Induced mutations have widely been accepted as a supplementary approach in the crop improvement programme, thus speeding up the breeding programme considerably.

Mutations can be induced using a variety of radiations including gamma- rays (^{60}Co, ^{137}Cs), X-rays, beta particles, neutrons etc. Among these, gamma-rays have been extensively used, due to convenience of handling and better penetrating power. Gamma radiations bring about mutagenesis by interacting with the DNA mainly causing single or double strand breaks. These DNA lesions can lead to simple mutations and chromosomal aberrations. Useful mutations are selected from a large number of random mutations. Among the induced mutants released world wide as varieties for cultivation, about 60% were produced using gamma rays. Some of the other physical mutagens include particle accelerators, electron beams and mutations induced by cosmic rays in space.

Crop improvement programmes at BARC employ radiation based induced mutagenesis along with recombination breeding in oilseeds (groundnut, mustard, soybean and sunflower), pulses (urdbean, mungbean, pigeon pea and cowpea), cereals (rice and wheat), and vegetatively propagated plants like banana and sugarcane. The desirable traits which have been bred through induced mutations include higher yield, improved quality traits, early maturity, disease and pest resistance, improved plant type, increased harvest index, semi-dwarf habit and abiotic stress resistance. Crop improvement programme makes use of the induced variability either by using the desirable mutants directly or by using them in cross-breeding to combine the desirable traits. Induction of modified traits and their incorporation in an ideal genotype could be achieved by a well planned and judicious use of induced mutation and hybridization techniques. Mutants or recombinants initially developed at BARC are evaluated in collaboration with the Indian Council of Agricultural Research (ICAR) or State Agricultural Universities in multi-location trials for various agro-climatic zones and the promising ones are released for commercial cultivation by the Ministry of Agriculture, Government of India (MoA, GOI). After notification, varieties enter into the seed chain of nucleus seeds, breeder seeds, foundation seeds and certified seeds. Certified seeds are supplied to the farmers for cultivation. With an effective blend of mutation and recombination breeding, 42 new crop varieties developed at BARC have been released and Gazette notified by the MoA, GOI for commercial cultivation. These include 21 in oilseeds (15-groundnut, 3-mustard, 2 soybean, 1 sunflower), 19 in pulses (8-mungbean, 5-urdbean, 5-pigeonpea, 1-cowpea) and one each in rice and jute (Table 1). The Trombay varieties can easily be identified by their names, which include the first letter T for Trombay where BARC is situated, the other letters indicate collaborating institutes e.g. TAU-1 is Trombay Akola Urid-1 where Dr. Punjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola is a collaborator (Table 1) .

III SOCIO-ECONOMIC IMPACT OF TROMBAY MUTANT VARIETIES

Some of the Trombay crop varieties have been very popular among the farming community. These are grown extensively in the country and have made a good impact on our National agriculture scenario by benefiting the farmers considerably. The Trombay pulse varieties are popular in Southern and Central India based on their high yielding ability and disease resistant characters. The blackgram variety TAU-1 is the most popular variety in Maharashtra. Based on the feedback received from Maharashtra State Seed Corporation, Akola and National Seed Corporation, Pune, they supplied over 21,013 metric tonnes certified seed of TAU 1 to farmers. Recently (2013) another blackgram variety TU-40 has been release for Andhra Pradesh, Karnataka, Tamil Nadu and Orissa. This variety is resistant to yellow mosaic virus and leaf spot disease and is suitable for rice fallows

In mungbean, major bottlenecks were the susceptibility of existing varieties for yellow mosaic virus and powdery mildew diseases. Successful incorporation for powdery mildew resistance in high yielding mutants resulted in powdery mildew disease resistant varieties TARM-1, TARM-2 and TARM-18 for the first time in India. The variety TARM-1 suitable for *rabi* and rice fallow cultivation became very popular in Orissa State. TMB-37 has been released for summer season, having early maturity (55-59 days) and yellow mosaic virus disease resistance that made available an additional area for mungbean cultivation under crop diversity programme. TMB-37 has become very popular in Madhya Pradesh, and is also being introduced in Bihar, West Bengal and Assam States. Subsequently, pyramiding for multiple disease resistance led to the variety TJM-3, which is the first variety released with multiple disease resistance to powdery mildew, yellow mosaic virus and *Rhizoctonia* root-rot diseases. This variety which was field tested in collaboration with Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, is very popular in MP. TM-96-2 is the first variety released for rice fallow cultivation in India, which is having powdery mildew resistance and synchronous maturity which are the essential traits for rice fallow cultivation, where nearly four million hectares of rice fallow area is available in India and considered prime area under crop diversity programme. This variety was field tested in AP in collaboration with N.G. Ranga Agriculture University is becoming popular in AP for rice fallow cultivation. Trombay pigeon pea TT401 and TJT-501 varieties are gaining popularity in the Central Zone comprising of Maharashtra, Madhya Pradesh, Chhattisgarh and Gujarat States. The recent addition (2014) is the high yielding pigeon pea TARA released for Maharashtra

Trombay groundnut varieties are very popular among the farming community and are cultivated throughout the nation in view of their higher yields, early maturity and better water use efficiency. Some of them have an additional useful trait of fresh seed dormancy of 20-30 days thus preventing *in situ* seed germination due to end season rains when the crop is ready for harvest. This trait is very useful under current changing climatic conditions wherein unpredictable rains are often experienced. Among the released TG varieties, TAG-24, TG-26, TG 37A, TG 38, TG 51 in normal seed class and TKG 19A, Somnath, TPG 41, TLG 45 in large seed class are popular among the farmers of major groundnut growing states such as Gujarat, Andhra Pradesh, Maharashtra, Karnataka, Orissa and Rajashtan and are also becoming popular in West Bengal, Punjab and Tamil Nadu, Madhya Pradesh, Uttar Pradesh and Goa. TAG-24 is the most popular TG variety grown throughout the country Farmers have been realizing the high yielding ability of groundnut varieties by harvesting record groundnut yields in many parts of the country. Hundreds of farmers were harvesting significant improved productivity even upto 7 tonnes/ha when recently released groundnut varieties were introduced in these states. One of the notable contribution of BARC has been in the development of early maturing confectionery grade large seed groundnut varieties (100-seed weight >60g) suitable for export and Table purpose. Existing large seed varieties were with long duration, longer seed dormancy and low productivity. However the recently released large seed mutant varieties like TBG (TDG) 39, TPG 41 and TLG 45 benefited many farmers by virtue of their earliness, moderate seed dormancy and superior productivity. Trombay varieties also facilitated farmers to develop newer cropping systems like intercropping groundnut with sweet corn, sugarcane; onion and use of polythene mulch technology for intensive groundnut cultivation.

Mutation breeding programme is also complemented with biotechnological approaches. Molecular markers are useful in crop improvement programmes for varietal identification, marker assisted selection, estimating genetic distances, linkage studies, phylogenetic analysis and tagging and cloning of desirable genes. Genomic assisted breeding and gene pyramiding for disease resistance and other economically important traits will help in hastening the mutation breeding programme. Mutated genes have also become a valuable resource to plant breeders and molecular biologists for understanding not only the function but also in isolating and shuffling the genes between varieties. At BARC, molecular markers have been used to tag agronomically important traits such YMV and bruchid resistance in urdbean; rust and late leaf spot resistance in groundnut; rust resistance in wheat and flowering time in *Sesbania rostrata*.

Some programmes at BARC in plant biotechnology are in the micro propagation of banana, pineapple, sugarcane, grapes and other economically useful plants. The tissue culture technique has been transferred to the user agencies such as Maharashtra State Seeds Corporation (Akola), Perunthalaivar Kamaraj Krishi Vigyan Kendra (Government of Pondicherry), Anandwan (Warora), Community Action for Rural Development Society (CARD, an NGO at Anjangaon-Surji) for commercial production and distribution to farmers. Cell culture/hairy root based production of bioactive compounds using bioreactor has also been developed. Studies have also been initiated for developing transgenic plants for disease resistance, for the production of edible vaccines and phytoremediation.

IV USE OF RADIOISOTOPES IN SOIL SCIENCES AND PLANT NUTRITION AND FATE AND PERSISTENCE OF PESTICIDES AND OTHER AGRO-CHEMICALS

Radioisotopes are used as a ‘tracer’ or ‘label’, which enable scientists to follow the movement of individual atoms and molecules in soil-plant system. The radioactive atoms reveal their presence by their radioactivity, which can be detected by suitable counters. The experiments using fertilizers labeled with radioactive isotopes facilitate the estimation of the optimum fertilizer requirement of plants, their biological transformations, translocation, the site of utilization in the plant, time of application, and also in quantifying their losses from soil. Radioisotopes are useful in generating information on mineral plant nutrition such as uptake of micronutrients etc using isotopes such as ^{59}Fe, ^{54}Mn, ^{65}Zn, ^{90}Mo etc. Patents for a new phosphorus (Patent no. 238485, 2010) and a zinc (Patent No. 239929, 2010) biofertilizer formulations have been obtained based on their evaluation using ^{32}P and ^{65}Zn as tracers [6,7]. The fate of the pesticides and other agro chemicals used in agriculture, their degradation products and their persistence in the ecosystem can also be studied using radioisotopes. For plant uptake and physiological studies, stable isotopes such as ^{15}N and ^{18}O are used as tracer. ^{14}C-labelled pesticides have played an important role in discerning the behavior of these agrochemicals in the environment. Model ecosystems have been developed and used in the laboratory to study the degradation of commonly used pesticides in Indian agriculture. Some of the fertilizers and agrochemicals labeled with a radioisotope such as ^{14}C, ^{35}S, ^{3}H and ^{32}P are tailor made by the Board of Radiation and Isotope Technology (BRIT), Department of Atomic Energy for use.

V INSECT PEST MANAGEMENT

Sterile insect technique (SIT) is gaining importance as an ecofriendly approach for the control of insect pests [2]. SIT includes mass rearing of target insect, inducing sexual sterility with radiation in adults (especially males) without affecting their mating vigour and competitiveness and release of such sterile adults in overwhelming number in natural population. This process limits the reproductive ability of natural population and brings down the insect population to a manageable level or even can eradicate completely. At BARC, attempts have been made to study SIT for controlling red palm weevil, potato tuber moth and spotted bollworm of cotton. Pheromones and bio-pesticides have also been developed for use in integrated pest management.

VI LAB TO LAND DEPLOYMENT FOR SOCIETAL BENEFIT

For the dissemination of research efforts of BARC to the farmers, effective linkages have been established with ICAR, State Agricultural Departments, State Agriculture Universities, National and State Seed Corporations, NGOs, National Institutes, Krishi Vigyan Kendras, progressive farmers etc. Large scale production of nucleus/breeder seeds is undertaken at BARC farms at Trombay and Gauribidanur, Karnataka and also in collaboration with progressive farmers and Agricultural Universities. Breeder seeds are supplied to different National and State Seed Corporations for multiplication into foundation and certified seeds to reach the farmers. Popularisation is also done through kisan melas, awareness programmes, science exhibitions and frontline demonstrations in farmers fields.

VII CONCLUSION

Our experience has shown that using radiations for crop improvement has come to stay as an efficient plant breeding method complementing the conventional methods. Clearly, the nuclear technologies have benefited the farmers, traders and end-users and will continue to play a significant role in addressing food and nutritional security.

VIII ACKNOWLEDGEMENT

Cooperation received from Indian Council of Agricultural Research, State Agriculture Universities, State Agricultural Departments, National and State Seed Corporations, NGOs and progressive farmers is acknowledged. I thank all my Divisional colleagues whose work has been cited in this article.

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Table 1:
Trombay crop varieties released and notified for commercial cultivation by Ministry of Agriculture, Government of India

Variety	Year of release	States	Special features
Groundnut			
TG 47 (RARS T1)	2011	ANDHRA PRADESH	Large seed, 115 days maturity
TDG 39/ TBG 39	2009/ 2008	KARNATAKA/ RAJASTHAN	Large seed, medium maturity, high oleic acid, more number of branches.
TG 51	2008	ORISSA, WEST BENGAL, ASSAM, NORTH EASTERN STATES	Early maturity, medium large seed, high shelling %, more 3-seeded pods
TLG 45	2007	MAHARASHTRA	Large seed, medium maturity
TG 38	2006	Orissa, West Bengal, Assam, North Eastern states	High shelling %, more 3-seeded pods, more round seeds, stem rot tolerance
TPG 41	2004	All India	Large seed, medium maturity, 20 days fresh seed dormancy, high oleic acid.
TG 37A	2004	Haryana, Rajasthan, Punjab, Uttar Pradesh, Gujarat, Orissa, West Bengal, Assam, North Eastern states	High yield, smooth pods, wider adaptability, collar rot and drought tolerance
TG 26	1996	Gujarat, North Maharashtra, Madhya Pradesh	Earliness, high harvest index, 20days seed dormancy, smooth pods, salinity tolerance
TKG 19A	1996	Maharashtra	Large seed size, 30 days fresh seed dormancy
TG 22	1994	Bihar	Medium large seed, 50 days fresh seed dormancy
TAG 24	1992	Maharashtra, Orissa, Karnataka, Rajasthan, West Bengal	Semi-dwarf, earliness, high yield, high partitioning %, wider adaptability
Somnath (TGS 1)	1991	Gujarat	Large seed, semi-runner type
TG 3	1987	Kerala	Less number of branches.
TG 17	1985	Maharashtra	No secondary branches, 30days seed dormancy.
TG 1	1973	Maharashtra	High yield, large seed, more branches, 50 days seed dormancy
Sunflower			
TAS-82	2007	Maharashtra	Black seed coat, tolerant to drought
Soybean			
TAMS 98-21	2007	Maharashtra	High yielding, resistant to bacterial pustules, *Myrothecium* leaf spot, soybean mosaic virus diseases
TAMS-38	2005	Maharashtra	Early maturing, resistant to bacterial pustule, *Myrothecium* leaf spot
Mustard			
TPM-1	2007	Maharashtra	Yellow seed Tolerant to powdery mildew
TM-2	1987	Assam	Appressed pod
TM-4	1987	Assam	Yellow seed

Mungbean (Green gram)			
TM 2000-2	2010	Chhattisgarh	Suitable for rice fallows and resistant to powdery mildew
TM-96-2 (Trombay Pesara)	2007	Andhra Pradesh (*rabi* and summer) and rice fallows	Resistant to powdery mildew and *Corynespora* leaf spot
TJM-3	2007	Madhya Pradesh	Resistant to powdery mildew, yellow mosaic virus and *Rhizoctonia* root –rot diseases.
TMB-37	2005	Eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam	Tolerant to yellow mosaic virus
TARM-18	1995	Maharashtra	Resistant to powdery mildew
TARM-1	1995	Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh, Kerala, Karnataka, Tamil Nadu, Orissa	Resistant to powdery mildew
TARM-2	1992	Maharashtra	Resistant to powdery mildew
TAP-7	1983	Maharashtra, Karnataka	Tolerant to powdery mildew
Pigeonpea			
TARA TJT- 501	2014 2009	Maharashtra Madhya Pradesh, Gujarat, Maharashtra, Chhattisgarh	High yielding High yielding, early maturing, tolerant to *Phytophthora* blight
TT-401	2007	Madhya Pradesh, Gujarat, Maharashtra, Chhattisgarh	High yielding, tolerant to pod borer and pod fly damage
TAT-10	1985	Maharashtra	Early maturing
TT-6	1983	Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Kerala, Andhra Pradesh	Large seed
Urdbean (Black gram)			
TU-40 TU 94-2	2013 1999	Andhra Pradesh, Karnataka, Tamil Nadu and Orissa Andhra Pradesh, Karnataka, Kerala, Tamil Nadu	Resistant to yellow mosaic virus and leaf spot disease. rice fallows Resistant to yellow mosaic virus
TAU-2	1992	Maharashtra	High yielding
TPU-4	1992	Maharashtra, Madhya Pradesh	Large seed
TAU-1	1985	Maharashtra	Large seed
Cowpea			
TRC-77-4 (Khalleshwari)	2007	Chhattisgarh (*rabi*)	Suitable for rice based cropping system
Rice			
Hari	1988	Andhra Pradesh	Slender grain type
Jute			
TKJ-40	1983	Orissa	High yielding

Abbreviations: A : Akola, AM : Amaravathi, B: Bikaner, D: Dharwad, G : groundnut, J : Jawahar, K: Konkan, K: Kendrapara, L : Latur, M : mung/mustard, MB: mungbean, P : Phule/Phaseolus (TAP-7), R: Raipur, R: Resistant (TARM-18)/Rabi (TARM-1,2), S : soybean/ sunflower, T : Trombay, T : tur, U : urid.