Application of Radiation Technology for Improving Crop Productivity

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Abstract

At BARC, in addition to crop improvement, several technologies have been developed to improve crop productivity. These technologies facilitate plant growth and yield by providing optimum growth conditions and protecting the crop from pests and diseases. Two such technologies that improve plant growth are highlighted here, viz., the application of radiation-polymerized superabsorbent hydrogels that improves soil moisture retention and its availability to the plants, and radiation-depolymerised chitosan that can act as a plant growth modulator. Sterile insect technique (SIT) is deployed to manage insect pest infestation. Male insects are exposed to low dose radiation rendering them sterile and then released in the field to compete with the native fertile males, which brings down the population of insect pests. Similarly, *Trichoderma* species are used as plant growth promoters and as disease bio-control agents. Using radiation-induced mutagenesis, an improved strain of *Trichoderma virens* has been isolated, formulated and extensively evaluated under field conditions, significantly improving yield in multiple crops.

Keywords: *Superabsorbent hydrogel, Chitosan, Sterile Insect Technique, Trichoderma*

1. Introduction

The three pillars of agriculture are crop improvement, crop production and crop protection. Optimum yield can be achieved if a suitable variety is grown with the right agro-inputs like fertilizers and irrigation, provided the crop is protected from damage by pests and diseases. In Nuclear Agriculture and Biotechnology Division of BARC, apart from crop improvement via mutation breeding, research is also done on application of nuclear techniques for improving crop productivity and for plant protection. Four focus areas are discussed herein, (a) improving water use efficiency (use of radiation-polymerised hydrogels), (b) plant growth stimulation and stress-tolerance (application of radiation-depolymerised chitosan), (c) protection from insect pests (sterile insect technique) and (d) plant diseases (improved biofungicides).

1.1 Radiation-polymerised super-absorbent hydrogel

Water is the most essential substance required by all life forms that exist on earth. Changes in climate including global warming have resulted in irregular monsoons. With changing rainfall patterns, an increasing average temperature of the environment, and prolonged shortage of water have contributed to drought in many areas in India. People are looking for ways to save water for various purposes majorly for different agriculture applications.

Superabsorbent polymer (SAP) materials are a particular class of synthetic macro-molecular network that can absorb and retain huge amount of water. These hydrogels are sometime referred to as magic water crystals that supply the reserved water to the plants and allow their unprecedented growth under arid conditions. However, SAP is a closely guarded technology and only few global giants have developed their own process technology with limited know-how, thus controlling its commercial applicability.

For the synthesis of SAP, acrylic acid monomers and polyacrylamide co-polymer are used employing various polymerization approaches like, suspension polymerization, solution polymerization and gel polymerization. Polyacrylate (the cross-linked polymer) is non-irritating and non- corrosive, but some natural polymers (polysaccharides and polypeptides) are also used for SAP formulations, as these are less expensive and are abundant. Superabsorbent polymer materials are currently being used in various fields including personal care (adult incontinence products, sanitary napkins, diapers, etc.), healthcare (wound dressing, medical waste solidification, absorbent mat etc.), agriculture, food packaging and oil drilling.

The use of SAP is an attractive approach of nourishing the soil. Its uses may however, vary depending upon region, environment and plants. For use in agriculture, SAPs, prepared using monomeric /polymeric precursor units, are considered as soil conditioners that have the capacity to absorb and hold up to 400 times water than their initial mass in the soil system. They are biodegradable with an annual degradation rate of 10-15% and absorption capacity index (ACI) in the range of 30-100. SAPs form granules upon swelling in soil which enhances soil properties like soil-moisture content and soil porosity. SAP is widely used for fulfilling the increased demand of food for growing population around the globe, and this is the key factor driving the demand for the SAP market in agriculture. Advancements on preparation of SAP formulations in last few decades involve co-polymerized composites for optimum stability and absorbency under load (AUL), controlled release of plant growth promoting factors, and also bio-based antifungal and antimicrobial SAP preparations. Driven by high demand from agriculture sector,the superabsorbent polymers are experiencing tremendous market growth and are attracting scientists as well as global market leaders for its advancement, low-cost production and potential utilization in agriculture to fulfill the societal requirements due to deteriorating climate conditions.

Nuclear Agriculture and Biotechnology Division (NA&BTD), Bhabha Atomic Research Centre (BARC) has developed superabsorbent polymer hydrogel (BARC-Hydrogel) using cold ionizing energy, such as gamma-rays and electron-beam, which makes it more eco-friendly compared to chemically synthesized process due to avoidance of harmful chemical cross-linkers. It can absorb and retain water up to several hundred times (≥550 times) of its own weight in pure water and supply upon plant-root demand through osmotic pressure difference (Fig. 1). In arid areas, the use of hydrogel in sandy soils (macro porous medium) increases the water holding capacity, which significantly improves the plant health and productivity.

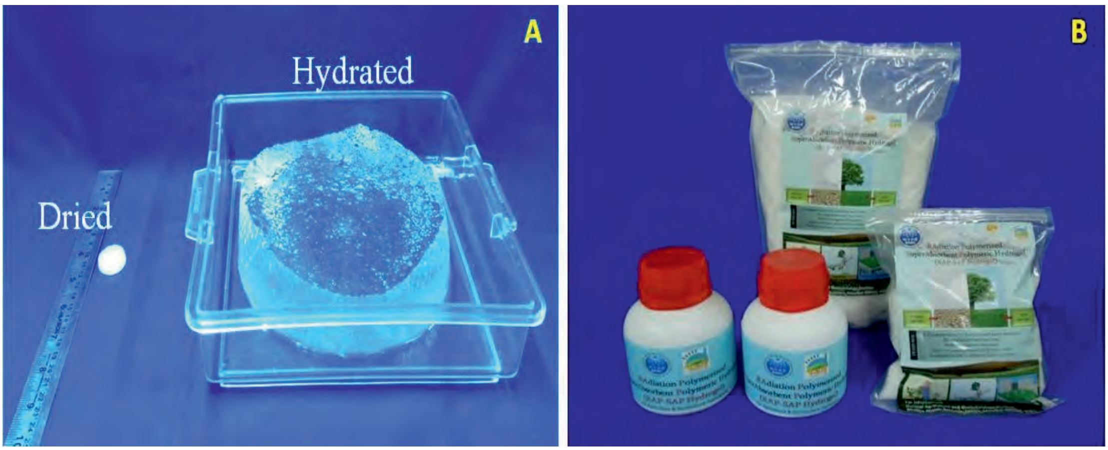

Figure 1: BARC-Hydrogel absorb and retain water up to several hundred times (≥550 times) of its own weight (A), and its available in different size packages

Features of Superabsorbent Hydrogel

- Soil augmentation by nutrient- and water-retention
- Bio-degradable and non-toxic
- Reduces irrigation frequency
- Improves hydro-physical properties ofsoil
- No impurities due to cold-energy based synthesis
- Reduces erosion and water run-off
- Enhances plant productivity, especially in arid areas
- Protects the environment against drought and ground water contamination
- Acts as an insulating material for plant roots in frosty winter conditions

Mode of Application (Fig. 2)

A. Direct mixing of dried SAP particles in soil
B. Pre-hydrated SAP hydrogel mixing in soil

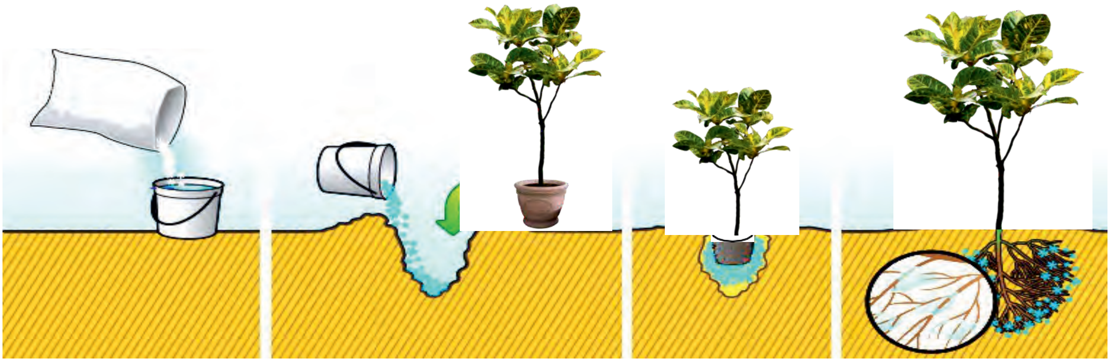

Figure 2: Hydrogel application to the soil before plantation

Application Areas:

Hydrogels can be applied for afforestation, agriculture, landscaping, vertical gardening, etc. (Fig. 3).

Figure 3: Various applications of hydrogel

Kinetic study of soil-moisture loss from the loamy and sandy soil in presence of SAP hydrogel (using two different particle size i.e. SP: small particles >500 µm; and LP: large particles 500-1000 µm) under day-light condition at temperature (~28°C) and humidity (50%), were compared with control (soil without SAP hydrogel), which showed that optimized hydrogel formulation mimic the soil nature and release water similar to the plain soil. However, due to the high water holding capacity, the hydrogel amended soil retained 50% water till day 40 in comparison to control (complete moisture loss in 15 days). Moreover, soil porosity and fluffiness was also found to be improved and maintained till the end of experimental observation (Fig. 4)

Figure 4: The addition of SAP increased the volume of soil by about 15%, giving it fluffiness. No change in the soil volume was observed even after day 40. (Note: 5 litre water used to saturate the 4.5 Kg of soil in each pot before starting the observations)

Figure 5: Under water-stress condition, wilting was observed much earlier in the plants growing in normal soil compared to SAP containing soil (A). Plants showed seedlingdirect on SAP hydrogel with root infiltration and branching (B). Growth of monocot and dicot plants in SAP hydrogel (no use of soil) for a period of one month under simulated environmental conditions, which reached to plant height more than one feet(C)

Preliminary analysis and effect of SAP in simulated environmental conditions showed (Fig. 5) improved plant health and also seedling and root development without any sign of stress. Open-field trials of BARC-hydrogel were performed on okra, banana, marigold, lemon croton, and maize at Trombay. Its application in reducing the water consumption up to 40% in water-intensive crops like banana, survival of plants in arid/drought conditions (>50% increase compared to control), 30% increase in size of kernels and seeds in maize, 20% higher flower biomass (in marigold), and ~30% higher yield in okra have been successfully demonstrated.

Figure 6: (A) BARC-Hydrogel application for afforestation on barren lands of LIGO- INDIA project location in Maharashtra (after 332 days), and (B) Urban tree-plantation application of BARC-Hydrogel (plantation of *Lagerstroemia speciosa* (Pride of India) by Director-BARC), and (C) *Saraca asoca* (Ashoka) trees (~ 80 plants) were planted at Indradhanush complex, Anushakti Nagar, Mumbai, which showed hydrogel promoted plant growth compared to control

BARC-hydrogel has successfully been tested for afforestation on barren lands of Hingoli, Maharashtra, with the help of Directorate of Construction, Services & Estate Management (DCSEM), DAE. It enabled survival of plants (neem and tamarind) by reducing water requirement upto 50%, and vegetative growth was comparable to control. After successful application of BARC-hydrogel in barren lands for water conservation, its first societal application has been initiated at Anushaktinagar, Mumbai, in association with DCSEM for plantation of *Saraca asoca* (Ashoka) trees. Approximately 80 plants were planted near the Indradhanush complex, which included equal number of control and Hydrogel-treated plants (Fig. 6).

The efficacy of BARC-hydrogel to conserve water is being demonstrated by reduction of 50% water irrigation in hydrogel-treated plants. BARC-hydrogel has also been tested on different garden plants of TIFR-Mumbai. BARC-hydrogel treated plants showed comparable growth with control under 40-50% reduced irrigation (Fig. 7).

Figure 7: BARC-hydrogel applications at TIFR garden

Climate change is leading to desertification in many areas including in India. Most of the areas intended for afforestation are characterized by a lack of moisture and mineral nutrients. Moreover, utilization of limited water resource to enhance the survival rate of plants will facilitate afforestation. Soil moisture recharge in these areas depends mainly on rainfall and on retention capacity of soil. Application of hydrogel is a good approach to improve water retention capacity of soils, characterized by the rainfall retention water management. Hydrogel prevents soils from crusting over, and increase their infiltration abilities for water, air and nutrients. These properties of hydrogels are used to improve water budget of sandy soils through prolonging of their moisture retention after rainfall.

BARC-hydrogel is a potential soil conditioner that can absorb rainwater or irrigation water several hundred times its mass. It can be applied wet or dry near the plant saplings at any time during the plant growth for providing plants an early and healthy start.

2. Irradiated chitosan as plant growth stimulator

Chitosan is composed of randomly distributed β-linked D- glucosamine and N-acetyl-D-glucosamine units. It is non-toxic, non-allergenic, biodegradable and biocompatible polymer, known to imparts multiple stress tolerance in plants [1]. Chitosan is derived from different waste materials, mainly wastes of fishery and sea food industries. Owing to its potential bioactive property, chitosan and its derivatives are immensely used in diverse fields including cosmetics, pharmaceuticals and agriculture. Biological effects of chitosan are mainly attributed to its antimicrobial (against pathogenic bacteria, fungi and viruses) and antioxidant (to encounter stress induced oxidative damages) activities, beside its growth promoting properties. The exogenous application of chitosan has been demonstrated to alleviate adverse effects of salinity and drought stress conditions [2-4].

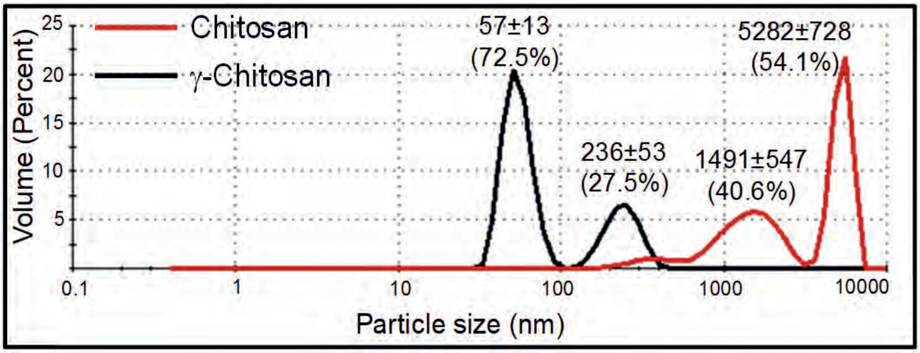

Figure 8: Dynamic light scattering analysis of chitosan and g-Chitosan. The size distribution range of chitosan and g-Chitosan was recorded using dynamic light scattering (DLS), at 100 ppm concentration. The refractive index was set at 1.34 for both chitosan and γ-Chitosan. Mean particle size (±SD) and relative abundance is given for each major peak

Chitosan mediated changes in plant cellular responses are dependent on the size of the chitosan (high/low MW), degree of acetylation and availability of functional group. The reduction in molecular weight of chitosan derivatives are known to increase its biological potential (in food, medicine/pharmaceuticals, agriculture, biotechnology and material science) over the unprocessed high-molecular weight chitosan. In addition, chitosan nanoparticles were shown to induce innate immune response in plants through up-regulation of defence related genes including that of several antioxidant enzymes as well as elevation of total phenolics [5]. Most of the currently used enzymatic approaches used for reducing the molecular weight of chitosan are although effective, but time-consuming, low productivity, costly and associated with the formation of toxic chemical by-products. In view of this, 100 kGy gamma radiation treatment was used for reducing the size of chitosan (designated here as γ-Chitosan). The dynamic light scattering recordings revealed the reduction in particle size from micro- to nano-meter range (Fig. 8). This size reduction can increase the bio-availability, which can positively improve the plant-growth stimulatory potential of chitosan. Apart from size, the other physical properties of chitosan also changed in response to gamma radiation (Table-1). In collaboration with VSI, Pune, it was shown that chitosan effects get intensified after gamma radiation in potato and sugarcane [6-7]. In continuation of this, studies have been conducted to evaluate the potential of γ-Chitosan for enhancing the arsenic stress tolerance in rice.

Rice is considered as one of the major staple food crops of India. There are multiple abiotic and biotic factors which causes drastic reduction in growth and productivity of rice. Arsenic (As) is a ubiquitous heavy metal and is recognized as the most prioritized human toxin by ATSDR-2017 (Agency for Toxic Substances and Disease Registry) and as group-1 carcinogen by IARC (International Agency for Research on Cancer). In addition to drinking water, another major

Table 1: Comparison of physical property between chitosan and γ-Chitosan

Parameters	Chitosan	γ-Chitosan
pH	3.17	3.17
Electrical conductivity	60	90
TDS	30	40
Viscosity (Centi poise)	250	15
Turbidity (OD600)	0.238	0.0086

route of As entry into humans is through the consumption of As contaminated rice and rice-based food products. The main reason behind the increase As level in paddy soil is through natural rock weathering and use of As-contaminated groundwater for irrigation. In the present study, the growth promotion effect of γ-Chitosan in rice was validated at naturally contaminated sites of Nadia district, West Bengal. The treatment was given in the form of seed treatment and two foliar applications at the time of pre-flowering and active grain filling. The plant height, tiller number and seed yield (kg/ha) significantly increased by 1.13, 1.38 and 1.35-fold in γ-Chitosan sprayed plants compared to water- spray control plants (Fig. 9).

Seeds were soaked either in 100 ppm γ-Chitosan or water for 6 h, and then plants were raised using normal agronomic practices. In addition to seed treatments, two foliar applications of γ-Chitosan (containing 0.01% Tween-20) were also given at pre-flowering and grain filling stages, which occurred at 50 and 65 days post-transplantation, respectively. Representative plant and flag leaves under water and γ-Chitosan-spray was shown qualitatively. The corresponding

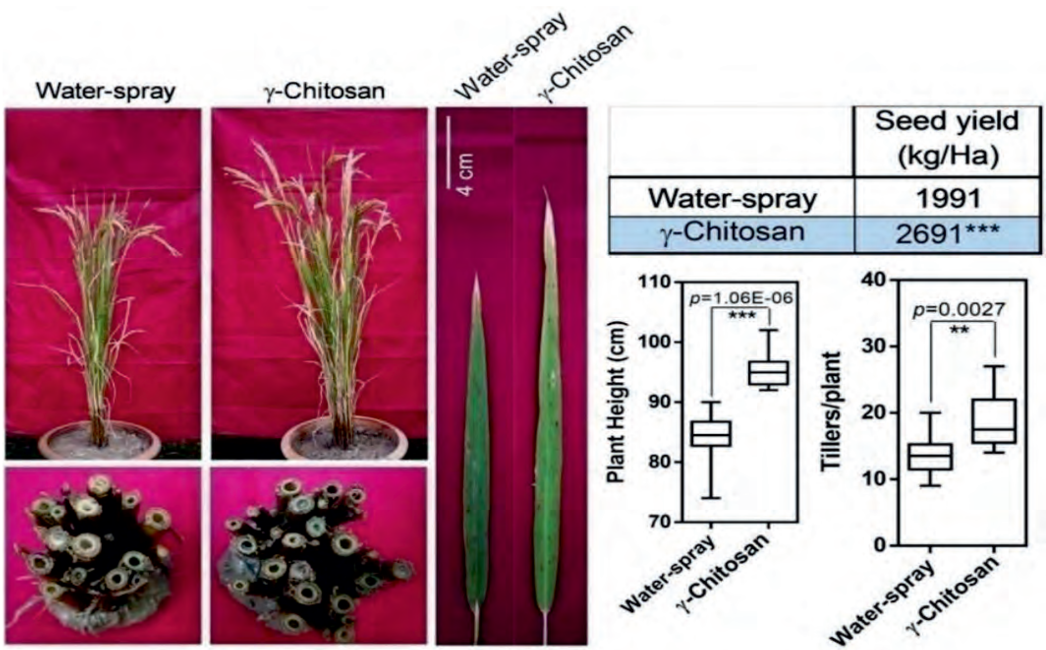

Figure 9: Field studies with Sambha Masoori rice variety under naturally arsenic-contaminated sites of Nadia district, West Bengal. Arsenic-contaminated site was selected in Nadia District (23°01'07.8"N-88°39'43.1"E, 23°01'14.3"N-88°38'24.7"E), West Bengal

transverse-section (at ~5 cm above root-shootjunction) was shown beneath to highlight the change in tiller numbers (A). The average seedyield, plant height and tiller number were quantified at the time of maturity (B). The mean values were compared based on *p*-values calculated using Student's t-tests

The foliar application of γ-Chitosan was also found to be effective on horticulture plants such as hydrangea and chrysanthemum. The selection of plants was done on the basis of their commercial value. For example, the *Hydrangea macrophylla* species, which are the native to Japan and Korea, are having multiple colors like blue, red, pink and purple. Most of the species are popular ornamental plants and also used as an herbal tea. The inflorescence of hydrangea has great commercial valve with a selling price of Rs.100 -150 per flower depending on their size. *Chrysanthemum morifolium* is another important commercial flower grown worldwide that gains its commercial value owing to its wide use in decoration, religious offering, garland making and medicines. The foliar application of γ-Chitosan in hydrangea led to 1.36-fold increase in average inflorescence size compared with those of water-spray control (Fig. 10A). Similarly, in chrysanthemum, the flower number and flower weight increased by 1.79- and 1.15-fold, respectively compared with those of water-spray control (Fig. 10B). In conclusion, γ-Chitosan can be considered as an effective, economic and versatile growth- promoting agent, for both grain crops as well as flowering plants.

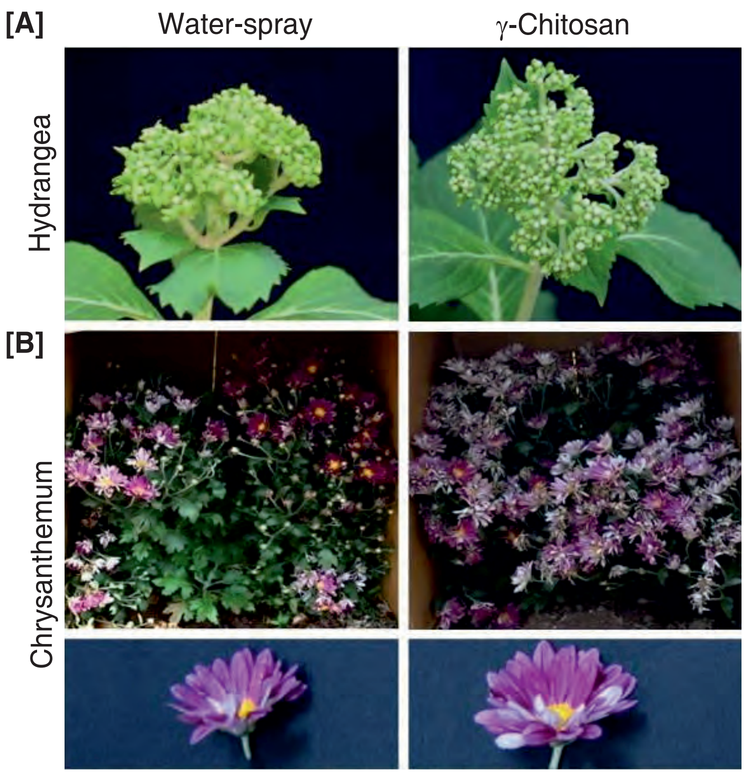

Figure 10: Pot-studies with γ-Chitosan on flowering plants. The effect of foliar application of γ-Chitosan was evaluated in Hydrangea (A) and Chrysanthemum (B) at BARC, Mumbai. Naturally grown plants were subjected to two foliar applications of 100 ppm γ-chitosan (containing 0.01% Tween-20) or water at vegetative and flower initiation phase

3. Sterile insect technique

Food crops, fruits and vegetables are commonly cultivated in most parts of tropical and subtropical regions of the world, and India contributes significantly to the total production. However, insect pests are the major biotic stress on different crops and affects around 25-35% of world food production. Insect pest management is challenging, currently various control strategies like insecticide cover-sprays, cultural and physical treatments, soil-drenches, use of pheromone traps, male annihilation technique (MAT), sterile insect technique (SIT), use of biorational products and release of natural enemies are being deployed to suppress the pest population [8]. Sterile insect technique is a form of birth control imposed on an insect pest population to reduce its numbers. SIT was conceived in the 1950s and successfully used to eradicate the Screw-worm fly (*Cochliomyia hominivorax*), a cattle pest from North and Central America. Since then, SIT has been used for prevention, suppression and eradication of various agricultural/horticultural and veterinary insect pest populations around the world [9]. Currently, gamma radiation from isotopic sources like Cobalt-60 (^{60}Co) or Caesium-137 (^{137}Cs) is the most widely used method to sterilize mass-reared insects for SIT programme. The principle of SIT involves release of sterile males in field which mate with females in the wild that fails to produce any offspring. SIT has been successfully implemented against a number of insect pest species such as Mediterranean fruit fly (*Ceratitis Capitata*); melon fly (*Zeugodacus cucurbitae*); pink bollworm (*Pectinophora gossypiella*); codling moth (*Cydia pomonella*), tsetse fly (*Glossina austeni*) [10] and more recently for mosquito control [11].

BARC is actively engaged in the development of SIT for the control of economically important insect pest in India. SIT has been developed for insect pests like red palm weevil, potato tuber moth and fruit fly species [12-14].


Figure 11: A) Red palm weevil (*Rhynchophorus ferrugineus*) and B) Red palm weevil infested coconut tree

Red palm weevil (RPW) (*Rhynchophorus ferrugineus*) (Fig. 11) is a serious pest of coconut and other palms in India and worldwide. Efficient and economical mass rearing methods were developed and sterility dose (15-20 Gy) was optimized [15]. Field studies were carried out to demonstrate the feasibility of this technology in collaboration with agricultural universities of Maharashtra, Karnataka and Kerala under coordinated BRNS project. The release of sterile RPW males in selected coconut growing hotspots resulted in significant reduction of wild red palm weevil population as well as decline in infested trees. Potato tuber moth (*Phthorimaea* *operculella*) is the most serious pest of potatoes in field as well as in storage. Studies were carried out to evaluate the feasibility of SIT for the control of potato tuber moth (PTM) under storage conditions. Mass rearing techniques have been developed and sterility dose (450-500 Gy) was optimized [12]. The feasibility of SIT in controlling population of potato tuber moth in storage was assessed in collaboration with Indian Council of Agricultural Research (ICAR) institutes. The growth of PTM population was significantly suppressed by the release of sterile PTM males.

Fruits and vegetables are the important horticultural crops in several states of India. The major constraints to fruits and vegetable production are the fruit flies (Tephritidae:Diptera) which cause 30-100% damage depending upon the crop and season [16]. Around 14 dacine species belonging to the genera *Bactrocera*, *Dacus* and *Zeugodacus* are serious pests in India. We have carried-out extensive survey to profile the distribution of fruit fly species in different states of India. Eight fruit fly species including *Bactrocera dorsalis*, *B. zonata*, *B. correcta*, *B. scutellaris*, *B. nigrofemoralis, Zeugodacus cucurbitae*, *Z. tau* and *Z. caudatus* were identified [14, 17, 18]. Among them, the Oriental fruit fly (*B. dorsalis*) (Fig. 12) and melon fly

Figure 12: A) Oriental fruit fly (*Bactrocera dorsalis*) and mango as host. B) Melon fly (*Zeugodacus cucurbitae*) and bottle gourd as host

(*Z. cucurbitae*) are the dominant species in India. The bacterial endosymbionts associated with insects including fruit fly play an important role in fitness of sterile insects and also other biological activities. The fruit fly species associated with various extracellular or intracellular endosymbiotic bacteria (*Wolbachia*) have been characterized through classical and molecular approaches [14,19,20]. The diverse bacterial communities that are associated with wild and mass-reared fruit fly, and their potential to use in fruit fly management has been assessed [21, 22].

The Oriental fruit fly is one of the major insect pests on economically important fruits such as mango, sapota, guava, etc. in India, and can damage 30-90% of fruit crops. We have standardised the economical mass rearing protocols based on natural host (sweet banana) and artificial diet to produce large number of *B. dorsalis* for SIT implementation. The optimized sterility dose (60-90 Gy) was determined by exposing mass-reared *B. dorsalis* pupae to gamma radiation [23]. This technology is being tested under field conditions in collaboration with agricultural universities and ICAR institutes of India.

The melon fly is a serious pest on cucurbits and solanaceous plant species and causes 30-100% damage. The mass rearing technique was developed for *Z. cucurbitae* by using natural host (Bottle gourd) and artificial diet in relation to SIT. The mass-reared pupae of melon fly were exposed to different doses of gamma radiation to identify optimized sterility dose (50-60 Gy) [23]. The feasibility of sterile males is being tested in field experiment in collaboration with agricultural universities and ICAR institutes of India.

Figure 13: Tomato infested with tomato leaf miner (*Tuta absoluta*) and damaged tomato field

The tomato leaf miner *Tuta absoluta* (Fig. 13) is one of the major invasive insect pests on tomato and other solanaceous crops. Occurrence of *Tuta* was studied by undertaking extensive survey in tomato growing regions of India [24] and the genetic diversity was studied using mitochondrial cytochrome c oxidase subunit I (COI) gene analysis [25]. *T. absoluta* samples revealed that there is no genetic variation within populations thereby making it an ideal candidate for SIT. The mass-rearing of tomato leaf miner was established on tomato seedlings and parasitism potential of different egg parasitoids (*Trichogramma* sp.) has been studied. Currently, we are working on development of SIT module for *Tuta* and integration of SIT with other biocontrol agents for the efficient management of tomato leaf miner.

In summary, Sterile Insect Technique (SIT) is an environmental friendly, species-specific and effective strategy to achieve area-wide integrated pest management (AW-IPM) of insect pests and has been successfully implemented in different countries. Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA) under the United Nations are engaged in supporting their member states in the development and application of environment friendly technologies. BARC has developed SIT technologies for the management of red palm weevil, potato tuber moth and fruit flies. Further, the feasibility of SIT for red palm weevil and potato tuber moth has also been demonstrated under field conditions. Field demonstration of SIT for fruit flies is in progress. The successful implementation of AW- IPM programmes integrating with other control strategies could help to suppress/eradicate the pest population in the field.

4. Genetically improved biofungicide

The filamentous fungi *Trichoderma* spp. are used widely as plant disease biocontrol agents [26, 27]. An improved *Trichoderma virens* strain has been developed at NA&BTD by gamma-ray induced mutagenesis (Fig. 14). This mutant produces up to 3-fold more anti-fungal compounds, and shows better protective activity against fungal infections of plants. In addition, many genes involved in plant disease biocontrol are up-regulated in this mutant [28]. A simple seed treatment formulation has been developed using tamarind seeds as the growth medium and talcum powder as the vehicle for delivery (Fig. 15). This formulation has been named as TrichoBARC.

Figure 14: *Trichoderma virens* wild type and mutant (Source: Ref. 28)

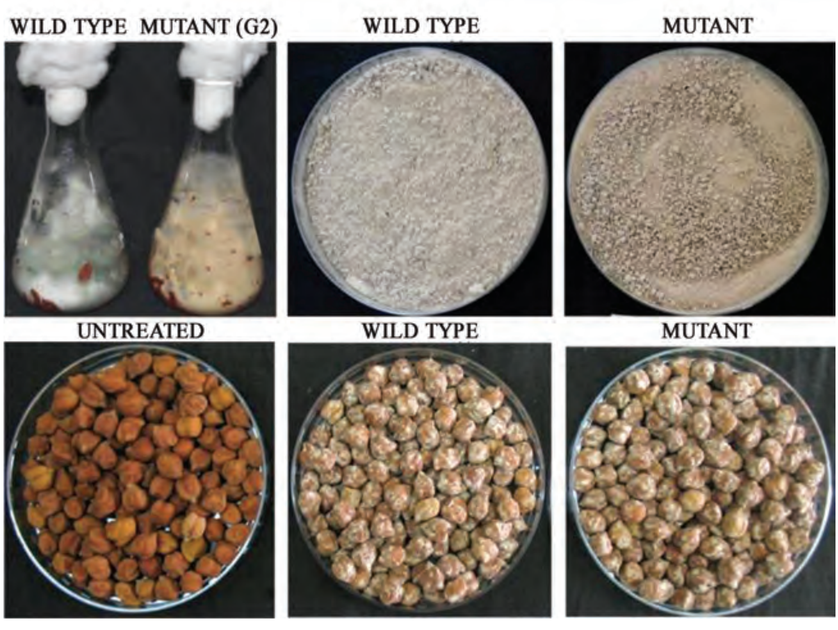

Figure 15: Growth of the wild type and mutant *Trichoderma virens* in tamarind seeds, formulation and seed treatment (Source: Ref. 28)

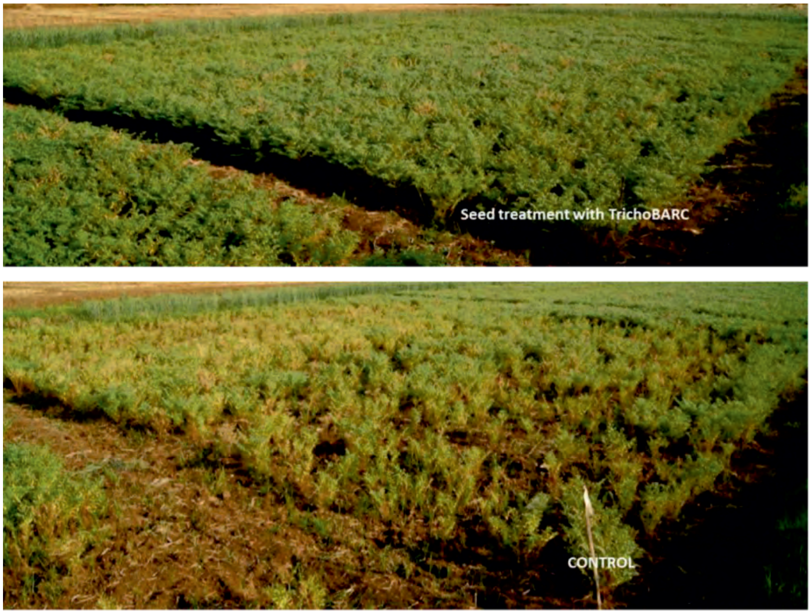

Figure 16: Demonstration of TrichoBARC seed treatment in chickpea, Raipur (2015-16) (Photo courtesy: Dr. Anil Kotasthane, Indira Gandhi Krishi Viswavidyalaya (IGKV), Raipur, Chhattisgarh)

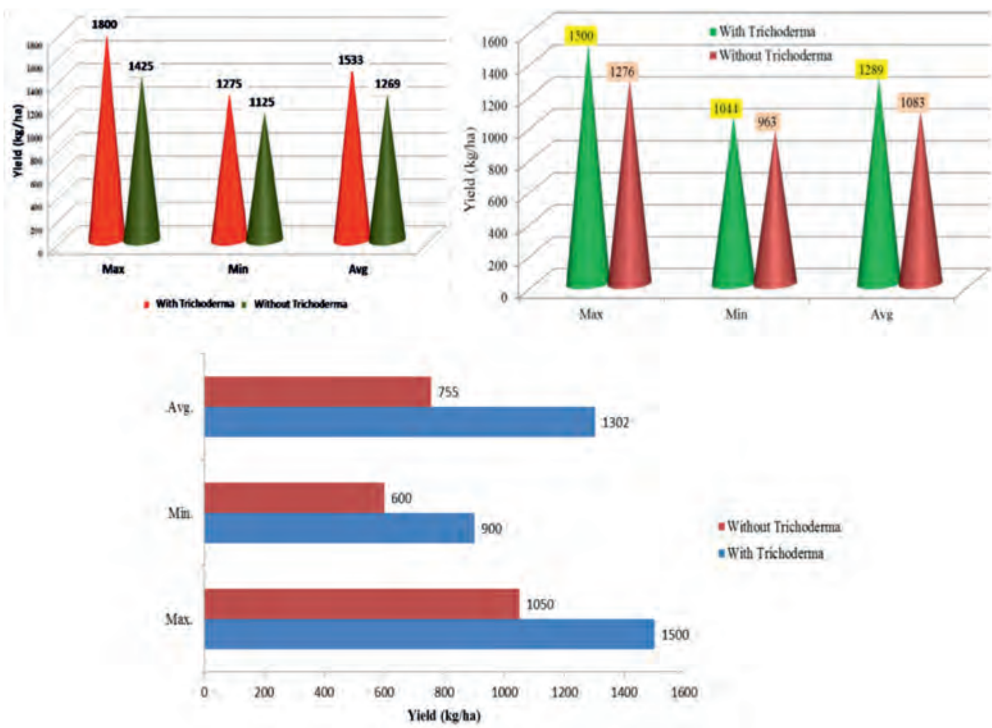

Figure 17: Field evaluation of TrichoBARC in lentil-farmers fields in 2017-18 (30 farmers), 2018-19 (30 farmers) and 2019-20 (10 farmers) in Nadia, West Bengal (Source: Ref. 28)

In 2015-16, the efficacy of the seed treatment technology was demonstrated on IGKV farm, Raipur (Fig. 16). This formulation has been evaluated at four locations selected from four states (UP, MP, Chhattisgarh and Assam) in an All-India Coordinated trial under ICAR. This simple and inexpensive seed treatment with TrichoBARC mutant significantly improved the yield at all the four locations in 2017-18 and 2018-19. The formulation has been extensively evaluated in demonstration plots and farmers' field in chickpea, soybean and lentil at Chhattisgarh (IGKV) and West Bengal (BCKVV). In all the trials, >20% yield improvement was observed which corresponds to increased profit of, on an average, Rs. 10000/ha while the seed treatment costs only Rs. 100/ha and is easily adoptable by farmers. In Nadia district of West Bengal, the trials

Control (Yield 12.5 q/ha) Treated (Yield 15.55 q/ha)

Figure 18: KVK trials in Kawardha, Chhattisgarh (2019) on effect of TrichoBARC seed treatment on soybean yield (Photo courtesy: Dr. Anil Kotasthane, IGKV, Raipur, Chhattisgarh)

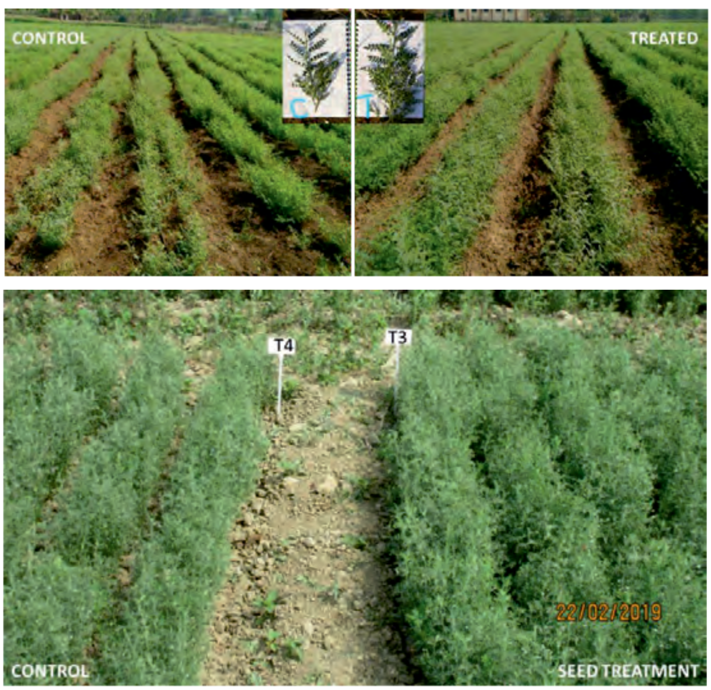

Figure 19: Effect of TrichoBARC on growth of chickpea (Upper panel) lentil (Lower panel). The field trials were taken-up in Chhattisgarh and West Bengal, respectively, in 2018-19 (Source: Ref. 28, and Dr. Rishu Sharma, Bidhan Chandra Krishi Viswavidyalaya (BCKVV), Mohanpur, West Bengal).

were taken in lentil-farmers' field (30 farmers in 2017-18 and 2018-19, and 10 farmers' in 2019-20). In all the three consecutive years, the TrichoBARC seed treatment very significantly improved yield in farmers' field. In 2017-18, the average yield (30 farmers' fields) in TrichoBARC mutant treated seed was 1533 kg/ha, as compared to 1269 kg/ha in control. The Figures were 1289 kg/ha (treated) and 1083 kg/ha (control) in 2018-19 and 755 kg/ha in control and 1302 kg/ha in treated plots (Fig. 17).

The formulation also improved plant growth and induced early (7-10 days) flowering under the field conditions in chickpea and lentil (Fig. 19). Toxicological data have been generated for this formulation and it has been found to be safe to mammals, fish, bird, earthworm and honeybees. The technology has already been transferred to two companies. A gene expression analysis revealed upregulation of 140 genes in the mutant, many of these being known to be involved in biocontrol properties like mycoparasitism, antibiosis and plant-interactions [28].

5. Conclusions and future perspective

Crops suffer immense yield losses due to abiotic and biotic stresses. Insect pests and diseases are major causes of biotic stresses, while non-optimal soil moisture and high and low temperatures are the major abiotic stresses in agricultural settings. The problem is compounded in the era of climate change and global warming. This chapter dwells upon use of nuclear technologies for mitigation of stresses resulting in significant yield gain. While sterile insect technique has great potential in managing insect pests, *Trichoderma* mutant-based seed treatment, in repeated field trials, has proven useful in controlling soil-borne plant pathogens, and also improving plant growth. These treatments are not crop-specific, and have broader implications in boosting agricultural productivity, in general. Similarly, radiation-depolymerised chitosan is effective in alleviating abiotic stresses as well as biotic stresses. Radiation-polymerised hydrogel holds great promise in areas where rainfall is low, with little or no irrigation facility. It would be interesting to combine various such treatments in the framework of an integrated crop management practice, and our future research will focus on this.

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