EVOLUTION OF STRATEGIES FOR CROP PROTECTION AND PRODUCTION

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Abstract

Nuclear Agriculture and Biotechnology Division (NA&BTD), Bhabha Atomic Research Centre (BARC) has an important programme on crop protection and production strategies, which includes developing sterile insect techniques (SIT), biopesticides for insect pests and plant disease control, and identifying suitable biomolecules for plant growth. The research activities in these areas were primarily focused on understanding the effect of gamma radiation on insects, mechanisms of insecticidal proteins, beneficial fungal strain improvement, developing effective biopesticides and detection of single to multiple pesticides through biosensors. The development of radiation based depolymerised chitosan and polymerized superabsorbent hydrogels that support plant growth and improves soil moisture retention, respectively. Further, the developed technologies were made available to farmers to integrate in the package of practices for crop cultivation towards reducing the negative effect of biotic and abiotic stresses.

1. Introduction and historical background

Crop protection is an important tool for enhancing food production worldwide. The management of insect pests and plant diseases as well as crop modifications are being undertaken through biotechnological approaches. The development of synthetic organic molecules (pesticides and antimicrobial agents) in the mid-1940s revolutionised the pest control strategies, but it caused negative effects on the environment and human health. However, practices with alternative approaches to the chemical agents were soon developed and continuously improved from the perspective of their application in crop protection and public health. The concept of integrated pest management (IPM) became popular after 1970, and attention was given to use of selective pesticides. Some of the prominent alternative approaches developed were: area-wide management of insect pests viz. Sterile Insect Technique (SIT) and use of hormones, pheromones, biocontrol agents etc. for eco-friendly management of insect pests. The SIT is an environment-friendly and autocidal insect pest control strategy in area-wide integrated pest management (AW-IPM) programme. Basically, SIT for target insect pest requires large scale mass rearing, sterilisation using ionizing radiation and periodic release of sterile males into the target area. The released sterile males would copulate with wild fertile females, leading to no offspring and further results suppression/eradication of the pest population. SIT has been implemented against several insect pests and vectors for prevention, suppression, containment, and eradication.

The use of radiation for the betterment of society was envisaged by Dr. Homi Bhabha with the establishment of Atomic Energy Establishment, Trombay (AEET) in Bombay. The biology research was initiated first on the campus of Richardson and Crudas at Byculla in Mumbai (then Bombay) in 1966 and later at BARC, Trombay. Pest Control Section was created under the leadership of Shri. G. W. Rahalkar, who took the reign of entomological research in BARC. Shri. Rahalkar and his team members, Dr. M. R. Harwalkar, Dr. H. D. Rananavare, Dr. A. J. Tamhankar, Dr. T. K. Dongre and others-initiated research on the effect of radiation on different insect pests. They have contributed to the monumental research work on understanding the impact of radiation on insects, developing mass rearing techniques, identifying orange eye mutant of potato tuber moth (PTM) *Phthorimaea operculella* (Zeller 1873)), SIT for red palm weevil (*Rhynchophorus ferrugineus* (Olivier)), Potato Tuber Moth, paddy stem borer (*Sirphiphaga incertulas* (Walker)), cotton bollworm (*Earias vittella* (Fab.) red cotton bug (*Dysdercus koneiji* F.) and diamond back moth (*Plutella xyleostella* L.), and research on pheromones, hormones and plant extracts for insect pest control. Field studies were carried out in collaboration with State Agricultural Universities (SAUs) and Indian Council of Agricultural Research (ICAR) to demonstrate the feasibility of SIT for insect pest management. Dr. S. V. Amonkar initiated the work on insect bio-control agents, plant extracts and entomopathogens, exploring their potential in insect pest and mosquito control. Some of the prominent insect pathogenic bacteria like *Bacillus thuringiensis* subsp. *kenyae* (Btk) ISPC-1 (H. Dulmage collection of the U.S. Department of Agriculture (USDA) is HD-549), *B. sphaericus* (Bs) ISPC-8 and *B. thuringiensis* subsp. *israelensis* (Bti) ISPC-12 have been isolated and tested against different insect pests and mosquito larvae.

Plant pathogens cause substantial yield loss in several field crops, leading in economic and social adversity. They attack plants, obtain nutrients, and cause disease by releasing effector proteins, enzymes, toxins etc. Currently, fungicides are used frequently to control these deadly plant pathogens. Moreover, soil-borne plant pathogens are very difficult to manage by using fungicides.

Table 1: Development of sterile insect technique (SIT) for major insect pest management at BARC

Insect pests	Host plants	Yield loss	Status/trials
Potato tuber moth	Potato, tomato, egg plant	60%	Field
Red palm weevil	Coconut & ornamental palms	25-100%	Field
Oriental fruit fly	Fruits and vegetables	30-100	Field cages
Melon fly	Cucurbits	70%	Field cages

Alternatively, usage of biocontrol agents in agriculture is an effective environment friendly approach to control plant diseases in the field. Towards this, different biocontrol agents like bacteria and fungi have been exploited in recent years. *Trichoderma* sp. is a fungus used for seed and soil treatment to manage various plant pathogens. In India, *Trichoderma viride* and *T. harzianum* were extensively commercialized as bio-fungicide for the control of soil-borne fungal diseases like *Fusarium* sp., *Rhizoctonia* sp., *Pythium* sp., *Sclerotium* sp., *Sclerotinia* sp. In BARC, several biocontrol agents have been isolated and tested against economically important plant pathogens. The R&D activities on *T. virens* started during 1990s and was extensively studied under laboratory and field conditions and proved to be effective against *Pythium aphanidermatum*, *Sclerotium rolfsii* and *Rhizoctonia solani*. A substantial amount of work has been done to understand the molecular mechanisms of biocontrol, identify novel genes, gene clusters and genome sequencing. Further efforts were made to develop an improved strain by using gamma radiation, which has been registered and commercialized.

Several technologies have been developed to improve crop productivity and food safety. During the 1980s, Enzyme and Microbial Technology Section was created under the leadership of Dr. S. F. D'Souza. He and his team members initiated work on immobilization of enzymes and microbial cells. Immobilization refers to any physico-chemical technique that immobilizes cells and biomolecules. It offers several advantages, including improved re-usability of precious biomolecules like enzymes, developing continuous bioprocesses, improved stability, and hence allowing its application in harsher environmental conditions. Initially, the focused was on continuous conversion of sucrose to fructose and gluconic acid by immobilized yeast cell multienzyme complexes using gamma radiation. Later, several enzymes and microbial cells were immobilised to develop various bioprocesses including bioremediation of metal ions and radionuclides. Recently, radiation-depolymerised chitosan that can act as a plant growth modulator and radiation-polymerized superabsorbent hydrogels have addressed water scarcity in agriculture to improve productivity. Further, immobilized biocomponents were used for the development of biosensors to detect single to multiple pesticides in food commodities.

2. Crop protection and production research at BARC

2.1. Recent developments in SIT and insect pathology

BARC is actively engaged in the development of SIT for the control of economically important insect pests in India (Table 1). Fruit fly species of Tephritidae family cause significant damage to fruits and vegetables. The population structure and distribution of fruit fly species in India has been studied. The Oriental fruit fly (*Bactrocera dorsalis*) is the most dominant species followed by Peach fruit fly (*B. zonata*), Guava fruit fly (*B. correcta*), Melon fly (*Zeugodacus cucurbitae*) and Pumpkin fruit fly (*Z. tau)*. The population dynamics of fruit fly species in mango and other fruits orchards in and around Dahanu region of Palghar district of Maharashtra was profiled. The performance of sterile males of *B. dorsalis*, *Z. cucurbitae* and *B. correcta* has been assessed in field cage experiments (**Fig. 1**). The sterile males were fully competing with non-irradiated males, which resulted in minimising the egg hatchability and suppressing the further generations. Currently, SIT module is being tested under pilot field conditions in collaboration with agricultural universities and ICAR institutes. Moreover, the tomato leaf miner (*Tuta absoluta* (Meyrick)) is an invasive insect pest of tomato and other solanaceous crops. The feasibility and integration of SIT with other biocontrol agents for this insect is evaluated in collaboration with ICAR-Indian Institute of Horticultural Research (IIHR), Bengaluru. The distribution, mass rearing protocols, sterility dose optimisation and performance of sterile males in polyhouse was studied. Inundative release of 150 Gy irradiated male moths at weekly interval was found to be effective in reducing number of live larvae per plant.

Fig. 1: Mass rearing, sterilization and evaluation of performance sterile fruit fly males in the field cages. (A) Mass reared fruit fly pupae; (B) and (C) field cages setup for releasing the sterile males in the presence of fertile males and females to estimate the competitiveness

2.2. Bacterial endosymbionts in pest management

Insects harbor many bacterial endosymbionts either intracellularly or extracellularly, and they play an important role in the biology and fitness of insects. Currently, certain bacterial endosymbionts are being explored for insect pest and vector management. *Wolbachia*, an endosymbiotic bacterium, is a intracellular reproductive parasite and is widely explored as a pest management tool. It has the ability to cause reproductive alterations such as feminization, thelytokous parthenogenesis, male-killing, cytoplasmic incompatibility (CI) and speciation through reproductive isolation. Association of *Wolbachia* with different fruit fly species (*B. dorsalis*, *B. zonata*, *B. correcta*, *B. scutellaris*, *B. nigrofemoralis*, *Z. cucurbitae*, *Z. tau* and *Z. caudatus*) was characterized by using 16S rRNA, Multi-Locus Sequence Typing (MLST) and *Wolbachia* specific protein (wsp) approaches. The prevalence of *Wolbachia* and other reproductive parasites varies with each fruit fly species and locations. The phylogenetic analysis showed that the majority of *Wolbachia* prevalent in fruit fly samples belong to Supergroup A and B which are parasitic in nature. *Wolbachia* inducing CI could serve as an important control strategy as "Incompatible Insect Technique" (IIT) for the control of insect pests including fruit flies and mosquitoes.

Bacterial communities associated with *B. dorsalis* and *Z. cucurbitae* were assessed by using culture dependent and molecular approaches (16S rRNA and Next Generation Sequencing analysis). We found varied relative abundance of bacterial communities in the gut of mass-reared or wild *B. dorsalis* and *Z. cucurbitae*. Enterobacteriaceae (61-73%) was the dominant family in *B. dorsalis* and *Z. cucurbitae*. Overall, these fruit fly species mainly host *Bacillus*, *Citrobacter*, *Enterobacter*, *Klebsiella*, and *Providencia* species. Gut microbiota associated with fruit fly species could help in developing efficient mass rearing protocol for SIT. Certain gut bacteria of fruit fly species attract the fruit fly adults e.g. cultural filtrate of *Bacillus*, *Citrobacter*, *Enterobacter*, *Enterococcus*, *Klebsiella*, *Pseudomonas* and *Raoultella* attracted different fruit fly species adults. Solid Phase Micro Extraction Gas Chromatography **(**SPME-GC-MS) analysis revealed 3-methyl-1-butanol, 2-phenylethanol, butyl isocyanatoacetate, 2-methyl-1-propanol and 3-hydroxy-2-butanone are the abundant chemical compounds in the supernatants of *K. oxytoca* and *C. freundii*. The chemical constituents identified from gut bacteria could be explored as attractants for eco-friendly insect control strategies.

2.3. Insect pathology-identifying novel insecticidal proteins

Various entomopathogenic bacteria have been isolated in BARC and biopesticides based on these bacteria have been developed. Insecticidal activity of these entomopathogenic bacteria is mainly due to the presence of several insecticidal toxins produced during the sporulation. *B. thuringiensis* subsp. *kenyae* ISPC-1 (**Fig. 2A**) produce insecticidal crystal (Cry) proteins during sporulation. Two prominent crystal toxins *viz.*, Cry1Ac17 and Cry2Aa14 from this isolate have been recombinantly expressed, purified and characterised. These are highly active against *Helicoverpa armigera* Hub. and *Spodoptera litura* (F.). Binary toxin, BinA (41.9 kDa) and BinB (51.4 kDa) of *B. sphaericus* ISPC-8 have been characterised and exhibit mosquito larvicidal activity. *B. thuringiensis* subsp. *israelensis* ISPC-12 (**Fig. 2B**) produce intracellular crystal inclusions during sporulation. These include four major, Cry4Aa (134 kDa), Cry4Ba (125 kDa), Cry11Aa (72 kDa) and Cyt1Aa (27 kDa) and two minor, Cry10Aa (78 kDa) and Cyt2Ba (29 kDa) insecticidal crystal proteins. The insecticidal toxicity is attributed to these toxins.

Xenorhabdus and *Photorhabdus* bacteria exhibit a mutualistic symbiosis with entomopathogenic nematodes belonging to Steinernematidae and Heterorhabditidae families, respectively. These bacteria are known to produce a variety of insecticidal toxins such as Xpt, XnGroEL, Txp40 and XaxAB toxins by *Xenorhabdus* and Tcs, Mcf, PVC and PirAB by *Photorhabdus*. Insecticidal activity towards target insects can score either through ingestion (oral route) or within their circulatory system (hemocoel). We have recombinantly expressed and purified the PirAB toxin and confirmed the insecticidal activity. The PirAB toxins share structural similarities with 3-domain Cry delta endotoxins from *B. thuringiensis*, suggesting a potential shared mechanism of action. On the other hand, Txp40 from *Xenorhabdus* possesses a unique structure with distinct N-terminal and C-terminal domains that enable the formation of a complex. This binding, along with its broad insecticidal activity against various insect pests, makes Txp40 a particularly interesting candidate for developing new insect pest control strategies that might be less susceptible to resistance.

2.4. Insect-plant resistance

Host plant resistance is the most economical and environment friendly means of managing insect pests. Identification of insect pest resistance has been explored through different breeding approaches including transgenics. The banana bunchy top virus (BBTV) is the major viral pathogen is transmitted by banana aphid causing disease in bananas and plantains worldwide. The detection of small interfering RNAs (siRNAs) derived from the ihpRNA transgene sequence in transformed BBTV-resistant plants positively established RNA interference as the mechanism underlying the observed resistance to BBTV. Efficient screening of transgenic plants showed resistant to BBTV infection. In groundnut, bruchid (*Caryedon serratus* Olivier) is a major storage insect pest damaging quality of stored groundnuts and impacting the market value. Screening of bruchid resistance in groundnut is difficult due to environmental variation and occurrence of biotypes. Thus, tightly linked markers or quantitative trait loci (QTLs) identification is required for further selection and pyramiding of resistance genes for stable resistance. Towards which, two common main QTLs were identified for bruchid resistance in groundnut.

2.5. Biopesticides for insect pest management

Several entomopathogens have been isolated and tested against different agricultural insect pests and mosquito larvae at BARC. Among them, *B. thuringiensis* subsp. *kenyae* ISPC-1, *B. sphaericus* ISPC-8 and *B. thuringiensis* subsp. *israelensis* ISPC-12 were found to be highly toxic to insect pests belonging to orders lepidoptera and diptera. Biopesticide based on *B. thuringiensis* subsp. *kenyae* ISPC-1 (AB03NABTD) has been evaluated in collaboration with State Agricultural Universities (SAU) and found effective against pod borer (*H. armigera*) on chickpea and pigeon pea crops. This biopesticide was included in multilocation trials under SAUs and All India Co-ordinated Research Project (AICRP) on chickpea of ICAR & showed effective in control of pod borer. *B. thuringiensis* subsp. *israelensis* (Bti) ISPC-12 is toxic to *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus* larvae. Granular formulation was developed using spore-crystal powder of Bti ISPC-12 and tested in simulated field conditions as per WHO guidelines. The spore-crystal powder (active ingredient) and formulation is safe to mammals and other animals as per toxicity tests carried out by Central Insecticide Board (CIB) approved toxicology laboratory. Field studies were carried out in Anushaktinagar, Mumbai and RRCAT township, Indore and resulted a significant mosquito larval population reduction in tested sites.

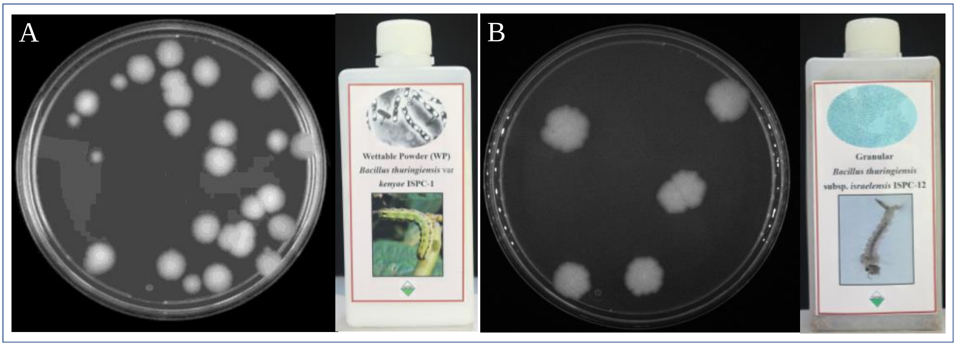

Fig. 2: (A) *Bacillus thuringiensis* subsp. *kenyae* (Btk) ISPC-1 and (B) *B. thuringiensis* subsp. *israelensis* (Bti) ISPC-12 used for characterisation of insecticidal proteins and development of biopesticide formulations

2.6. Biopesticides for plant disease management

2.6.1. Induced mutagenesis of Trichoderma virens

Trichoderma virens is an important beneficial fungus used for the control of soil borne plant pathogens. The potential biocontrol agents must have a higher degree of bioefficacy and should be amenable to mass production. During 2001, genetic improvement of *T. virens* was initiated through radiation-induced mutagenesis. Towards this, wild *T. virens* strain (**Fig. 3A**) was exposed to 1250 Gy gamma rays and different purified colonies exhibiting distinct morphological features have been selected for further research. Different mutant isolates were screened for antifungal activity, antibiosis, secondary metabolite production, *in vitro* and *in-vivo* inhibition of plant diseases. A mutant strain designated as G2 with dark pigments in the medium and brown colour conidia (**Fig. 3B**) was selected for further study. The liquid culture filtrate of G2 strain was shown higher inhibition than the wild type against *P. aphanidermatum*. This G2 mutant isolate has been deposited as a novel mutant strain with microbial type culture collection vide no. MTCC 11567. *T. virens* G2 mutant isolate is producing several secondary metabolites such as viridin and viridiol. Transcriptome analysis of G2 mutant and the wild-type strain revealed upregulation of several secondary metabolism biosynthesis, transport and mycoparasitism-related genes like polyketide synthases, O-methyl transferases, cytochrome P450s, oxidoreductases, glycosyl hydrolases, and MFS transporters in this mutant.

2.6.2. Bio-fungicide for plant disease management

The field application of *Trichoderma* spp. requires mass multiplication, which can be done using solid or liquid state fermentation. Solid state fermentation is preferred in India due to low initial investment as well as availability of agro byproducts. In India, tamarind seeds are available as a byproduct and can be stored for a longer time. Further, tamarind seeds contain high organic matter in the form of carbohydrates, proteins, fats and are suitable for fungal multiplication. Tamarind seeds exhibits intrinsic sticking properties and abundant in xylo-glucan. Thus, tamarind seeds can be easily covered with formulation without incorporating sticker. A tamarind seed based solid-state media was developed in-house for mass production of *T. virens* G2 strain. This mutant strain grows profusely and appears brown (conidia colour) within 10 days. A wettable powder bio-fungicide (TrichoBARC) (AB18NABTD) was developed based on *T. virens* G2 strain (**Fig. 3C**) and is currently used for seed treatment.

Fig. 3: (A) Morphological features of wild type *Trichoderma virens* and (B) G2 mutant strain of *T. virens*. (C) Commercial formulation based on mutant strain (G2) of *T. virens* available as "VIREN" for soil borne plant pathogens control

TrichoBARC was found to be effective in suppressing major soil borne plant diseases such as collar rot, seed and root rots and also damping off. During 2015 to 2023, multi-location field trials were conducted with G2 strain in collaboration with SAUs and ICAR and found to be highly effective against collar rot of chickpea. In parallel, toxicity data were generated for this formulation and this technology has been transferred to five industries for commercialization as on August 2024. Recently, Central Insecticide Board and Registration Committee (CIB & RC) approved grant of registration for indigenous manufacturing of above formulation (1% WP) of mutant strain (G2) of *T. virens* for the control of collar rot (*S. rolfsii*). To the best of our knowledge, this is the first mutant biopesticide have been registered anywhere in the world for commercial application. The product ("VIREN") based on this technology has been launched in the market. Recently (2023 - 2024), the G2 strain formulation has been recommended as Package of Practice (PoP) for controlling soil-borne disease of chickpea, cumin and cluster bean by ICAR and Agriculture University, Jodhpur, Rajasthan. Presently, the mutant formulation is being further evaluated at various SAUs and ICAR.

3. Newer biomolecules for plant growth and biosensors for pesticide monitoring

3.1. Plant growth promoting formulation: "Anu-Chaitanya"

Millions of tons of crustacean's shells are cast aside each year by the seafood industry, creating environmental concerns. A major component is chitin (20-30%), a valuable resource exhibiting considerable functional properties that have led widespread exploitation of chitosan as a versatile, high-value bioactive substance. Chitosan and its derivatives are finding exciting uses in a wide range of fields, from cosmetics and pharmaceuticals all the way to agriculture. Unlike chitin, chitosan is soluble in acidic aqueous solutions, significantly expanding its practical applications in agriculture. Although formulation of chitosan nanoparticles can be achieved through traditional methods, it might not be economically viable owing to time extensive, low quality product synthesis and expensive (like using enzymes). Besides, some methods might create harmful chemicals in the process. Therefore, the application of gamma radiation (100 kGy) has been explored for the formulation of chitosan nanoparticles offering a promising and potentially more sustainable alternative (**Fig. 4A**).

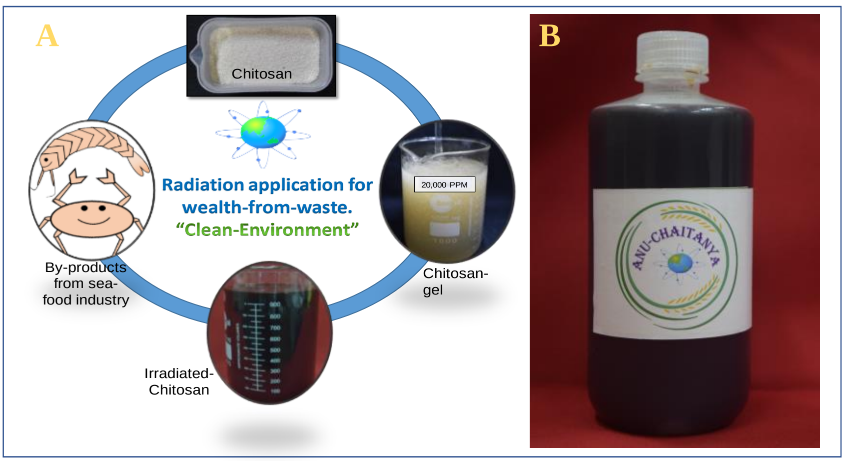

Fig. 4: (A) Application of gamma radiation on chitosan to obtain depolymerized chitosan. (B) "Anu-Chaitanya" product was developed and employed as plant growth promoter on field crops and flowers.

In collaboration with Vasantdada Sugar Institute (VSI), Pune and BARC have developed gamma-radiation based chitosan formulation named "Anu-Chaitanya" (**Fig. 4B**) (AB52NABTD). About 99 % homogeneity in the particle size (30-100 nm) was achieved under 100 kGy dose. In addition, viscosity and turbidity was also reduced post-irradiation. Successful field trials demonstrated improved plant growth potential of Anu-Chaitanya in potato, sugarcane and other crops, including flowering plants like Hydrangea and Chrysanthemum and forage crop like tall fescue.

4. Superabsorbent BARC-Hydrogel (MRIDAMŔT) (मृदाअमृत)

Changes in climate, including global warming, have resulted in irregular monsoon across the globe. The changing rainfall pattern along with prolonged shortage of water and an increase average temperature in the environment have led to drought and arid conditions in many areas. Drought and arid conditions adversely affect the plants growth and its productivity. Moreover, shortage of water availability for routine irrigation is an important aspect contributing towards crop production. In BARC, radiation-polymerised hydrogels were developed to address the water scarcity in agriculture, horticulture and plantations. A radiation polymerized hydrogel known as Superabsorbent BARC-Hydrogel (MRIDAMŔT) (मृदाअमृत) (AB51NABTD) was developed (**Fig. 5**). The production process is eco-friendly in nature as compared to chemically synthesized processes due to the elimination of harmful chemical cross-linkers. This material can absorb and retain water up to several hundred times (>550 times) of its own weight and maintain a slow and sustainable release of water supporting plant growth. Dry granules of BARC-Hydrogel enhance soil properties by retaining more water and improving aeration for plants. Eco-friendly nature of hydrogel formulation helps plants to survive and maintain good health in semi-arid and arid regions and conserve water by reducing the frequency of irrigation. The use of hydrogel in macroporous medium (sandy soil) is very effective to increase the water holding capacity, which significantly improves the plants health and productivity.

Fig. 5: Development of superabsorbent BARC-Hydrogel.

6. Biosensors for detection of pesticides

Due to the extensive use of pesticides in agriculture and other allied sectors, the presence of pesticides in food commodities and their entry into the food chain has become a major concern all over the world. Crop protection and food safety have become crucial for all involved in the value chain, and consumers have to be assured that they are not exposed to an unacceptable level of pesticide residues. BARC has initiated research on the development of biosensor-based technologies for the monitoring of pesticides using different immobilized biocomponents.

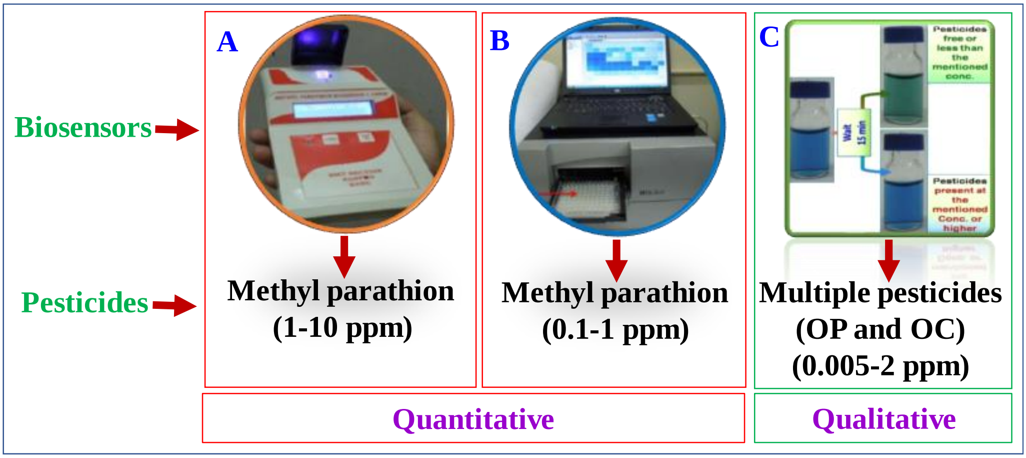

Fig. 6: Development of biosensor-based technology for pesticides detection ranging from single to multi sample analysis. (A) Hand held optical biosensor device for field use; (B) Microplate based biosensor for multiple samples in laboratory and (C) Biosensor Kit (Biokit) for the qualitative detection of multiple pesticides. OP: Organophosphates and OC: Organocarbamates.

The concept of microbial biosensors was established by immobilizing microbial cells on different matrices and associated with various transducers for the detection of methyl parathion pesticide in single to multiple samples. Later, Handheld Optical Biosensor Device (**Fig. 6A**) was developed by employing microbial enzyme in the immobilized form which helps to detect methyl parathion pesticide directly in the field (AB28NABTD). Further, microplate-based biosensor (**Fig. 6B**) was developed to detect methyl parathion pesticide in multiple samples in the lab (AB35NABTD). Moreover, the concept of enzyme-based biosensors was strengthened for the qualitative detection of multiple pesticides (12 types of pesticides including 6 banned pesticides) belonging to the organophosphate (OP) and organocarbamate (OC) groups. This outcome was translated into technology of Biosensor Kit (Biokit) (AB37NABTD) (**Fig. 6C**). The working protocols and results were validated from the pesticide testing laboratory. This technology was certified by State Food Analyst, Assam and FSSAI also recognized Biokit as Rapid Food Testing Kit. These technologies have been transferred to different entrepreneurs (14).

7. Way forward

Insect pests and diseases affect agricultural sustainability and pose a challenge for food security. In addition, climate change is altering pest behaviour and geographical distribution, which may further increase the risk of introducing invasive insect pests and diseases to new areas. Crop protection and production research has consistently included both basic and applied aspects for protecting the crop damage by insect pests and diseases and enhancing the crop yield. Currently, efforts are being made to support farmers in the transition to achieve the ambitious targets of the 'Lab to Land Strategy'. At BARC, working on new crop protection and production technologies and continuous research support for enhancing crop production and productivity will be carried out at a sustained pace. SIT, implications of bacterial endosymbionts, identifying novel insecticidal proteins to minimize the resistance development in insect pests, developing resistant plant materials, developing suitable biopesticides for insect pest, vector and disease control have been carried out to suppress major pests and disease in crops. The radiation depolymerised chitosan is effective against biotic and abiotic stresses, while radiation-polymerised hydrogel supports moisture retention in the soil during low rainfall or less irrigation facilities. Further, development of biosensors for detection of multiple pesticides from various groups of pesticides was undertaken. These technologies significantly improve plant health and productivity. Peaceful application of nuclear energy for crop improvement and protection through molecular and nuclear techniques like mutation breeding, SIT, microorganism strains and biomolecules improvement will be further explored. Newer areas of research including microbial, molecular, biochemical and information technology methods could support the ongoing programmes which will facilitate in improving methodologies, processes and also enhance cost-effectiveness for crop protection and production technologies.

8. Acknowledgements

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