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The Role of Nuclear Technology in Agriculture Sector: Case Study of India

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Abstract

For India's economic development, the agriculture sector is crucial for reducing poverty and guaranteeing food and nutritional security. Innovative technologies and agricultural research provides answers to present and future agricultural challenges in India. To meet the world's population's food needs in a satisfactory manner, the FAO forecasts that agricultural production must expand by 60 percent to meet the predicted increasing demand for food. Agricultural and food systems must be modified to support food security and reduce poverty. This is where nuclear technology comes into play. It provides sustainable solutions that boost productivity and hence the living standards of growers and breeders while conserving natural resources.

While nuclear power and nuclear weapons are the most common applications of nuclear technology, there are numerous additional applications of nuclear energy, one of which is agriculture. Nuclear technologies are playing an important role in agricultural technology development, assisting rural communities in increasing crop yield, controlling pests and diseases, and improving water quality. Nuclear science and technology have a significant impact on improving global access to a safe, secure and high-quality food supply. Scientists and farmers are constantly creating new methods of cultivating crops and raising livestock applying nuclear technology that have been proven safe and successful. So, this article focuses on how nuclear energy (radioisotopes) and its related technologies is a gift to the world rather than its catastrophic applications. It briefly describes the role of nuclear technology in agriculture and ensuring food security with special reference to India.

Keywords: Nuclear Technology, India, Agriculture, Food Security, Sustainable Development.

Introduction

> A growing plant is a chemical factory, of course. Scientists have known this for years-but haven't known exactly what went on in that factory. They didn't know and couldn't find out how chemicals enter the plant, what the chemicals did, and how they accomplished their work. So, agriculture has had to depend on trial-and-error in producing vital food. Now agricultural science has perfected a way for studying and following plant chemicals from the time they leave the soil until they are finally deposited in the various parts of the plant. By mixing small quantities of radioactive isotopes with the soil, the scientist, with his Geiger counter, can now follow the movement of important chemicals through the whole cycle of plant life. . . . Food production, therefore, is passing from trial-and-error to certainty (Oatsvall 2014, 368).

Nuclear science and technology provide techniques for increasing production while conserving vital resources used in daily living. Radioisotopes are utilised in research to create new strains of agricultural crops that are drought and disease resistant, of greater quality, grow faster, and yield more. During decay, radioactive materials release a variety of radiations and energy particles that are used in medicine, agriculture, and physical sciences for basic research and a wide range of applications (Sahoo and Sahoo, 2006). Radioactive exposure increases agricultural product quality and productivity, as well as helps in insect-pest management. They aid in the study of the most effective use of fertilisers, insecticides, and pesticides in cultivated crops while causing no harm to plants or other living things. Radioisotopes have played an essential role in increasing agricultural output in a sustainable manner. Ionising radiation is extremely beneficial in the preservation of agricultural and food items. Various everyday items have profited from radiation in some way throughout their manufacturing.

The International Atomic Energy Agency (IAEA) advocates for the increased use of radioisotopes and radiation sources in science, industry, agriculture and medicine. The Food and Agriculture Organisation (FAO) and the International Atomic Energy Agency (IAEA) collaborate to facilitate the development and implementation of nuclear technologies at the national and international levels in order to improve agricultural output. The Joint FAO/IAEA Division's purpose is to create enhanced nuclear-based technologies for long-term food security. Crop enhancement, food preservation, determining groundwater resources, sterilising medical supplies, analysing hormones, X-ray pipelines, controlling industrial operations, and studying environmental contamination all involve radioisotopes and controlled radiation. FAO and IAEA collaborate to fund and coordinate global research initiatives on the use of isotopes and radiation in irrigation and agricultural productivity, soil fertility, insect and pest control, livestock production, health and food preservation. Agriculture improvement is one of the most important contributions that atomic energy can make to meeting the challenge of food security for present and future generations, conserving natural resources, and protecting the environment (IAEA, 1996). In India, the Bhabha Atomic Research Centre (BARC) plays an important role in promoting nuclear agriculture, which helps in crop improvement, plant studies, food and crop management etc. Since the 1950s, BARC has been involved in mutation breeding in India using ionising radiations such as x-rays, beta particles, gamma rays, and electron beams.

Role of Nuclear Technology in Agriculture

Higher Crop Production

It is commonly understood that the yield of any crop is dependent on the amount of the supply of nutrients and water. Fertiliser, which is required in current agricultural practices to maximise crop yields, will continue to be in high demand in order to feed the world's fast growing population. Radioisotopes can be used to "label" various fertilisers. By attaching radioactive tracers to known volumes and kinds of fertilisers, it is feasible to directly quantify the corresponding nutrient efficiencies as the labelled products are absorbed at key locations in the plant. This technology can be used to significantly reduce the quantity of fertiliser needed to produce robust yields, lowering farmer costs and minimising environmental damage.

Water is a vital aspect in agricultural production, and it is becoming increasingly scarce in many parts of the world. Neutron moisture gauges, which measure the spectrum change caused by energetic neutrons colliding with protons, may measure the hydrogen component of water in both the plant and the surrounding soil. As such, they are perfect tools for assisting farmers in making the best use of limited water supplies (Walter 2003, 26). Another effective method for increasing crop production is the development of new species - varieties that can withstand heat or storm damage, have earlier maturing times to avoid frost damage and allow crop rotation, resist diseases and droughts, provide better growth and yield patterns, provide improved nutritional value, allow for improved processing quality, and so on. Specialised radiation techniques, such as directly blasting seeds to modify DNA structures or irradiating crops to induce variety in the subsequent seeds, can significantly speed up the selection process (IAEA 1995).

Radiation-induced mutations have increasingly contributed to the improvement of crop plant varieties during the last two decades, and they have become an established feature of plant breeding procedures. In many nations, radiation-induced mutation trials are yielding encouraging findings for improving farmed crop varieties. By employing radiation energy to induce mutation, BARC has generated a number of high yielding varieties of tur, green gram, black gram, groundnut, jute and rice (Sood et al., 2010). Many national authorities have recognised the value of crop varieties generated by induced mutations, and they have been released and approved for commercial cultivation.

India is the world's leading producer of radioisotopes. Trombay's research reactors DHRUVA, CIRUS, and APSARA produce a wide range of radioisotopes. Radioisotopes are also produced by the Nuclear Power Corporation of India Ltd.'s power reactors and the accelerator at the Variable Energy Cyclotron Centre in Kolkata. BARC's crop improvement research has resulted in the production of 23 high yielding varieties of diverse crops that have been introduced for commercial agriculture. There are ten pulse types, nine groundnut varieties, two mustard kinds, and one jute and rice variant each. Trombay research and development has led in the optimisation of plant water and fertiliser use, monitoring of pesticides in groundwater, and understanding the role of pheromone chemicals in insect control. The technique of growing tissues artificially in a culture medium is known as tissue culture. For this technology, BARC is a significant research and development node. BARC has transferred the tissue culture-based seed development technology to the Maharashtra State Seed Corporation, Akola. This corporation has established a tissue culture lab and is supplying farmers with saplings. The Pondicherry Government has also received tissue culture technology. The Centre has standardised pineapple micro-propagation on a vast scale. The banana cultivars created at Trombay using the tissue culture method have produced encouraging yields in agricultural settings. 12 types of banana that are significant economically have a protocol for cultivation (DAE 2023). The majority of groundnut and black gram farmed in India are mutant types developed at BARC. Many similar effective mutants are in use in other nations, such as high yielding mutant barleys that can utilise larger dosages of fertiliser for improved grain production. In India, an improved pearl millet line with resistance to downy mildew disease was produced via irradiation treatment and is now farmed on several million hectares.

New crop varieties were created through recombination breeding and radiation-induced mutagenesis. Numerous mutants with varied desired features have been developed in diverse crop plants at BARC using radiation-induced mutagenesis. A total of 55 varieties, including crops like groundnut, rice, mustard, cowpea, sunflower, jute, linseed, soyabean, mungbean, and pigeon bean, have been released and officially announced for commercial cultivation across the nation from 1973 to 2022 using such mutants. These Trombay varieties are widely grown and have high public acceptance. Trombay varieties have been successfully developed and disseminated all across the country thanks to synergistic research collaborations and Memoranda of Understanding (MoU) between BARC, ICAR institutes, and State Agriculture Universities (Badigannavar et al. 2022, 204). BARC has used a variety of strategies to spread Trombay varieties all throughout the nation. In order to raise awareness of the Trombay varieties, it has taken part in exhibitions, Kisa Melas, and field demonstrations under the Public Awareness Programme on Peaceful Uses of Atomic Energy.

Food Processing

Demand for healthy food with a long shelf life is increasing in both developed and developing countries. 25-30 percent of the world’s produce is lost owing to spoilage by microorganisms and pests, with developing countries bearing the brunt of the losses (WNA 2021). Food waste can be avoided by using effective food preservation methods. Radiation can be used to kill bacteria in food and manage insect and parasite infestations in harvested food to reduce waste and deterioration. Irradiation can extend the shelf life of certain foods by a few days, which is enough to keep them from rotting. Food irradiation offers the potential to provide safe foods with an extended shelf life. By carefully exposing certain seeds and canned foods to radiation, they can be stored for longer periods of time. When compared to traditional techniques of preserving food for a similar shelf life, food irradiation saves energy (Wilkinson and Gould, 1996). It has the potential to reduce the world's food shortage by minimising post-harvest losses. Food irradiation can replace or dramatically reduce the usage of hazardous food additives and fumigants that are harmful to both customers and employees in food processing companies. Irradiation does not heat the food, hence it retains its freshness in its physical state. Irradiation eliminates the agents that cause spoiling (microbes, insects, etc.) from packaged food, and packing materials are impervious to germs and insects, preventing recontamination. Food irradiation kills insects and parasites, inactivates bacterial spores and moulds, prevents microbe and insect reproduction, inhibits root crop sprouting, delays fruit ripening, and improves food technological qualities.

Food irradiation is the process of exposing food to carefully controlled doses of ionising radiation, such as beta particles or gamma rays, in order to break the DNA bonds of microorganisms. This is particularly efficient at disrupting the reproduction cycle of bacteria and diseases. It has the ability to eliminate undesirable organisms as well as particular non-spore-forming harmful pathogens such as salmonella. It can also disrupt physiological processes like sprouting in potatoes or onions. As a result, the shelf life of many foods can be significantly extended, and the presence of food-borne diseases caused by organisms such as Escherichia coli can be significantly reduced. One of the primary benefits of food irradiation is that it sterilises food without changing its form or flavour. Older food processing technologies that rely on heating or freezing, excessive drying or salting, or chemical treatments usually alter the taste or appearance of food (Walter 2004, 51).

Irradiation can also be used on prepared foods. This is especially important when it comes to meals for astronauts, hospitals, or disaster relief (earthquakes, floods, etc.). In this situation, the food is packaged in a material that does not degrade when exposed to radiation, the packaging protects the food from coming into contact with bacteria and becoming contaminated. Radura is an international logo that appears on the packaging of irradiated food (IAEA 2019, 52). Irradiation has been recognised by the FDA as a way of inhibiting sprouting and delaying ripening in many fresh fruits and vegetables. The FAO and IAEA divisions worked closely with the World Health Organisation (WHO) to encourage international acceptability of irradiated food (WHO 1998).

The Food Corporation of India estimates that due to insufficient storage facilities, 10 to 15 percent of grain production is lost. According to information from the Ministry of Food Processing Industries, each year 230 lakh tonnes of grains, 120 lakh tonnes of fruits, and 210 lakh tonnes of vegetables are spoiled annually. The Ministry of Food and Civil Supplies of the Government of India reports that each year, rotting results in the loss of about 22 percent of the entire wheat production. According to FAO, almost 40 percent of the fresh fruit and vegetable production in India perishes before reaching customers. In this context, gamma irradiation technology can be extremely important for food security and safety. It is a potential food safety technology for removing the primary disease-causing microorganisms, E. Coli, Campylobacter, and Salmonella from food (Saravanan et al. 2021, 92).

The nation's food security has greatly benefited from the research and development being done at BARC in the area of radiation technology applied to agricultural and food processing. The following has been the current operation of DAE's four facilities for food radiation processing:

- Defence Laboratory in Jodhpur, Rajasthan, and the radiation processing facilities for research and development in Trombay.
- High-dose facility built by BRIT in Navi Mumbai for processing radiation on spices and other goods.

- Located in Lasalgaon, district of Nashik, Maharashtra, Krushak (Krushi Utpadan Sanrakshan Kendra) is a low dose radiation processing facility for controlling onion sprouts and preserving agricultural produce (DAE 2023).

BARC has developed technology to increase the shelf-life of various products such as fruits, vegetables etc. which helps in maintaining the quality and taste of these foods, which further helps in boosting the exports. Recent studies conducted by the Food Technology Division of BARC in the field of food irradiation have revealed several extremely intriguing uses of radiation processing, including enhancing fragrance attributes, antioxidant status, and shelf life extension of minimally processed products. Pre-cut vegetables and minimally processed vegetables are among the ready-to-cook (RTC) products that are becoming more and more popular with consumers. These goods give consumers convenience by omitting preliminary work including sorting, washing, peeling, and chopping. Several minimally processed vegetables have successfully undergone BARC shelf life extension. These products retain their nutritional benefits, including their carbohydrate, protein, fat, vitamin, and mineral content. Utilising gamma-radiated, chemical-residue-free pre-cut veggies in the near future can greatly reduce the post-harvest losses (30-40%) of these vegetables by assisting in their processing into easily prepared, ready-to-eat/cook, and shelf-stable products (Gupta and Variyar 2021, 79). Many countries have given permission for food gamma irradiation. The Government of India's National Monitoring Agency (NMA) has approved the radiation processing of onions, spices, and frozen seafood (Sood et al., 2010).

Plant Nutrition Studies

Fertilisers are very expensive, and optimal application is critical for lowering agricultural crop production costs. It is critical that the maximum amount of fertiliser applied during cultivation enters the plant and that the least amount is lost. Radioisotopes can be used to estimate the amount of phosphorus and nitrogen in the soil. This assessment aids in deciding the amount of phosphate and nitrogen fertiliser to apply to the soil. Fertilisers marked with radioactive isotopes like phosphorus-32 and nitrogen-15 have been used to research fertiliser intake, retention, and utilisation. Excessive fertiliser use reduces biodiversity and harms the environment. These isotopes can be used to calculate the quantity of fertiliser consumed and lost to the environment by the plant (Harderson 1990).

Nitrogen-15 is also useful in determining the amount of nitrogen fixed by plants from the environment in field conditions. IAEA develops and disseminates systems for assessing nutrient uptake from diverse fertiliser sources using radioactive isotopes in order to produce greater and more stable grain yields by optimising nutrient uptake from applied fertilisers. The crop absorbs only a modest amount of fertiliser supplied to the soil. The remainder either remains in the soil or is lost through a variety of processes. FAO and IAEA have collaborated on various research projects aimed at maximising the use of radioactive isotopes for fertiliser management practises in essential agricultural crops such as wheat, rice and maize (Zapata and Hera, 1995).

The study of soil characteristics is immensely useful in developing effective farming strategies. Radioactive isotopes can be employed as “tags” to monitor plant uptake and utilisation of critical nutrients from soil (IAEA, 1996). This technology enables scientists to determine the fertiliser and water requirements of crops under certain conditions. The availability of sufficient water is a critical aspect for successful crop production.

Nuclear moisture density gauges can monitor and figure out the moisture content of soil, indicating the precise irrigation requirements of a specific area. Nuclear science and technology have considerably aided such investigations, and they are now frequently employed in soil plant nutrition research to make the most use of limited water resources. Ionising radiation is also used to sterilise soil, and there is currently a lot of interest in using radiation to eradicate bacteria in the soil that cause diseases and are damaging to plant growth (Kaur et al. 2013, 169).

Insect-Pest Management

Insect pests are responsible for severe reductions in agricultural crop productivity around the world. Insect pests pose a significant danger to agricultural productivity. Not only do they diminish crop production, but they also spread disease to farmed crops. Radiolabel pesticides were used to track the persistence of pesticide residues in food, soil, ground water, and the environment. These research have aided in the identification and mitigation of pesticide and insecticide adverse effects. There are concerns that continuous pesticide usage has a harmful influence on the ecosystem and leads to the development of pesticide resistance in many insect species. Furthermore, pesticides kill not only the target species but also many other beneficial pest species that help to preserve natural ecological balance in crop areas (Kaur et al. 2013, 169).

The sterile insect technique is an effective technique of using nuclear technology to control or even eradicate hazardous insects. This entails bulk “factory breeding” of enormous numbers of the target insects and sterilising the males using gamma irradiation. When sterilised males are reintroduced into infested areas and mate with wild females, no offspring are produced, the pest will be eradicated if the sterilised men considerably exceed the wild males in the area (Walter 2004, 50-51). It has been used successfully to remove many insect pests of agricultural importance all over the world. It has been used successfully to eradicate the Mediterranean fruit fly from the United States, Mexico and Chile, as well as screw worm infestations in the United States and Mexico (Wyss, 2000).

The development of SIT for the management of economically significant insect pests in India has been vigorously pursued by BARC. For insect pests such the red palm weevil, potato tuber moth, and fruit flies, SIT has been developed (Tripathi et al. 2021, 60). Among the significant studies and innovations at BARC are: Poly-ammonium phosphate fertiliser and biopesticide bacillus thuriengiene to suppress agricultural insects, the synthesis of several insect pheromones, methods for assessing soil nutrients, and pheromone chemicals for controlling sweet-potato moth and cotton moth (DAE 2023).

Livestock

Sustainable livestock management is critical to global food security. It must take into account both the expanding global human population's desire for animal-derived foods and the issues posed by climate change. IAEA develops animal health and production practises using nuclear methods to assist meet this demand while protecting natural resources. Nuclear and nuclear-related immunological and molecular technologies, serve vital and frequently unique roles in animal health management. They are simple to use, fast, sensitive, specific, and resilient, and can provide significant benefits over other methods. This includes point-of-care use, which helps veterinary authorities, extension agencies, and farmers control and remove diseases that harm animal productivity and health (IAEA 2012).

Stable isotope ratios allow for the tracking of animal movements, allowing for a more accurate assessment of the risks of disease transmission. Pathogens exposed to controlled doses of gamma irradiation enable the development of attenuated vaccines containing metabolically active but non-replicating pathogens capable of inducing a strong immunological response and memory, particularly in cases of parasitic diseases that cause significant production losses globally.

The IAEA, in collaboration with the FAO, assists Member States in developing and implementing nuclear-based technologies to optimise livestock reproduction and breeding practices that are consistent with sustainable development principles, support animal production intensification, and optimally utilise the world's natural resources. Iodine-125 radioimmunoassay of hormones can identify pregnant animals in dairy herds, which can subsequently be used to lower the fraction of non-productive animals engaging in breeding. Cobalt-60 can be utilised to create whole-genome radiation hybrids (RH) panels and RH mapping of livestock species and breeds, allowing for better animal breeding.

To better understand the complex dynamics between plant nutrients, water, and the effects of livestock farming in various regions of the state of Tamil Nadu (Kancheepuram, Trichy, Erode, and Madurai), the Tamil Nadu Veterinary and Animal Sciences University used nuclear techniques in the current project. The outcomes attained thus far are remarkable:

- Production of cow milk increased by about 15 percent in each of the four locations.
- By reducing the calving interval from 13 to 12.2 months in Kancheepuram, 15 to 12 months in Trichy, 17 to 14 months in Erode, and 14 to 13 months in Madurai, dairy cow reproductive performance improved in all four locations (Zaman 2017).

Conclusion

It is projected that by 2050, the world's population will be expanded by one-third, with developing nations experiencing the greatest increase, and with it, our needs for sustainable food and water. Nuclear technologies provide innovative and often unique solutions to combat hunger and malnutrition, promote environmental sustainability, and ensure food safety. The application of nuclear technology in agriculture has shown to be a potent and cutting-edge instrument for overcoming the difficulties of contemporary agriculture. Nuclear technology has made a substantial contribution to raising crop yield, boosting soil fertility, and assuring food security. This contribution dates back to its inception with the creation of radiation-induced mutation breeding and continues with more sophisticated applications like isotope techniques. Numerous high-yielding and resilient crop varieties that can tolerate a number of environmental challenges, pests, and diseases have been developed with the use of radiation-induced mutation breeding. As a result, agricultural output has increased, helping to meet the rising demands of a rapidly growing world population.

Additionally, the understanding of plant nutrient intake, water management, and soil fertility has benefited greatly from the use of isotope techniques. Scientists can monitor nutrient uptake and water movement in plants and soils by utilising isotopes as tracers, which optimises resource usage and lowers waste. Agricultural practices have become more effective and sustainable as a result of this knowledge. Further, the use of nuclear technology in food preservation and insect management has reduced the need for toxic pesticides and minimised post-harvest losses. In addition to improving food quality and safety, this has helped lessen the negative environmental effects of traditional agricultural methods.

Despite these advantages, there are several drawbacks to the application of nuclear technology in agriculture, such as public worries about radiation, safety, and potential abuse. In order to allay these worries and guarantee the proper application of nuclear technology in agriculture, appropriate legislation, strict safety procedures, and broad public awareness campaigns are needed.

In the future, continued research and development in this field hold great promise for further advancements in agricultural practices. In order to fully use nuclear technology and create a world that is more robust, sustainable, and food secure, collaborations between scientists, politicians, and agricultural communities will be essential. We can create a better agricultural future that promotes global food security and protects our planet's natural resources by utilising the advantages of nuclear technology while carefully controlling its hazards.

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