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Nuclear Technology in Horticulture: Boosting Productivity, Controlling Pests, Conserving Water

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Horticulture faces significant challenges due to the destruction of crops by pests and diseases, both before and after harvesting, resulting in a significant reduction in crop production. Nuclear technology has emerged as a valuable tool for enhancing agricultural productivity. Despite the common association of nuclear technology with energy and weaponry, its use in Horticulture is diverse and multifaceted. Physical mutagens such as nuclear radiation, including gamma rays, X-rays, and UV light, as well as particle radiation, can be employed to induce chromosomal breakages, cross-linking of DNA strands, nucleotide deletion, and substitution. UV rays can be used to irradiate cell suspensions and pollen grains in the early or late uninucleate phases. Through the application of nuclear technology, agricultural productivity can be improved by increasing crop yields, controlling pests and diseases, and enhancing water quality. Food preservation can also be

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achieved through food irradiation, where ionizing radiation is applied to target pathogens to break their DNA bonds. Nuclear technology can also be utilized to induce beneficial mutations in crops through genetic modification, sterilization-based pest control, and water usage management. In conclusion, nuclear technology presents an innovative and effective solution for addressing challenges in Horticulture, thus contributing significantly to global food security.

Keywords: Mutagenesis; sterile insect technique; crop improvement; food irradiation; water use efficiency.

1. INTRODUCTION

Although nuclear technology is mostly associated with nuclear energy and weapons, it has numerous applications in Horticulture. These technologies have significantly contributed to the development of horticultural practices by promoting crop production, disease and pest control, and improved water quality. Physical mutagens, including electromagnetic radiation such as gamma rays (emitted from radioactive cobalt-60), X-rays, UV light, and particle radiation such as fast and thermal neutrons, alpha and beta particles, have been utilized in these applications. Ionizing radiation, for example, induces chromosomal breakages that facilitate cross-linking of DNA strands, nucleotide deletion, and substitution [1]. Non-ionizing physical mutagens such as UV rays have also been used to irradiate cell suspensions and pollen grains in the late or early uninucleate phases due to their low penetration. Additionally, various radioisotopes such as P^{32} ($t_{1/2}$ 14.3 days, β 1.7 mev, γ 0), C^{14}($t_{1/2}$ 5570 yrs,, β 0.155 mev, γ 0), Ca^{45}($t_{1/2}$ 165 days, β 0.254 mev, γ 0), H^3 ($t_{1/2}$ 12.46 yrs, β 0.018 mev, γ 0), Na^{22}($t_{1/2}$ 2.58 days, β 0.54 mev, γ 1.28 mev), Na^{24}($t_{1/2}$ 15.05 hrs, β 1.39 mev, γ 1.368 to 2.754 mev), Co^{60}($t_{1/2}$ 5.24 yrs, β 0.31 mev, γ 1.17 to 1.33 mev), Cu^{64}($t_{1/2}$ 12.9 hrs, β 0.57 mev, γ 1.34 mev), Fe^{55} ($t_{1/2}$ 2.94 yrs, β 0, γ 0), Fe^{59}($t_{1/2}$ 44..3 days, β 0.271 mev, γ 1.30 mev), Mn^{54}($t_{1/2}$ 314 days, β 0, γ 0.84 mev), K^{42}($t_{1/2}$ 12.47 hrs, β 3.58 mev, γ 1.51 mev), Rb^{86}($t_{1/2}$ 18.68 days, β 1.82 mev, γ 1.08 mev), S^{35}($t_{1/2}$ 89 days, β 0.168 mev, γ 0), Zn^{65}($t_{1/2}$ 246 days, β 0.325 mev, γ 1.12 mev) are readily available in sufficient quantities and have been widely employed to address several problems of interest in Horticulture and other domains. Horticulturists have utilized several radioisotopes for conducting seed germination studies. For instance, P^{32} has been applied to examine phosphorus uptake in seeds, while C^{14} has been utilized to study carbon fixation and metabolism. Ca45 has been employed to analyze calcium absorption and transport in plant roots, and H3 has been used to study water uptake and movement in plants. To investigate ion uptake and transport in plant roots, Na^{22} and Na^{24} have been utilized.

Moreover, a study (Srivastava, et al., [2]) investigated the effects of gamma radiation emitted by ^{60}CO on Gladiolus plants. The exposed plants exhibited significant changes compared to the control group. Gamma radiation influenced plant height, leaf size, and overall plant structure. Flowering patterns were also modified, resulting in alterations in flower size, color, and shape, as well as the occurrence of deformities and changes in floral symmetry. Reproductive capacity was negatively impacted, leading to reduced production of viable seeds and decreased pollen fertility. Additionally, gamma radiation caused variations in chlorophyll content, photosynthetic efficiency, and antioxidant enzyme activity. These findings underscore the importance of radiation safety measures in horticulture and highlight the necessity for further research to comprehend the underlying mechanisms and develop strategies to mitigate radiation-induced damage in ornamental plants. Mn^{54} has been applied to study manganese uptake and transport, and K^{42} has been utilized to investigate potassium uptake and transport. Apart from these, several other radioisotopes such as Rb^{86}, S^{35}, and Zn^{65} have been used for various studies related to plant growth and nutrient uptake [3].

2. BREEDING NEW SEED VARIETIES

Radiation generation resulted to seed types which have better yields. One well-known case of a successful crop is the "miracle" rice which has elevated the price of rice manufacturing substantially. Crop development in trendy includes genetic variation, skewed in the direction of greater beneficial developments. Different varieties of radiation can be used to initiate those mutations for crop improvement. Traits that the researcher’s intend to deliver

Table 1. List of Fruit cultivars generated with the induced/natural mutation

Fruit crops	Cultivar	Year	Mutagens	Improved fruit traits
Mango	Rosica	1966	Spontaneous mutation	Large and good quality
Apple	Golden Haidegg	1986	γ-rays	Fruit size
	McIntosh 8F-2-32	1970	γ-rays	Skin colour
	Senbatsu-Fuji-2-Kei	1985	γ-rays	Fruit colour
Grapefruit	Rio Red	1984	thN	Fruit colour
	Star Ruby	1970	thN	Seedless
Indian jujube	Mahong	1986	thN	Round, pink rose sweeter taste
Loquat	Shiro-mogi	1981	γ-rays	Fruit size
Orange	Xuegan 9-12-1	1983	γ-rays	Seedless
	Hongju 420	1986	γ-rays	Seedless
	Eureka 22	1987	X-rays	Fruit set, fruit quality
	Valencia 2	1987	X-rays	Fruit quality
Peach	Magnif	1968	γ-rays	Large, red skin
	Plovdiv	1981	γ-rays	Large, fruit quality
Sweet cherry	Lapins	1983	X-rays	Larger size, firmer
	Compact Lambert	1964	X-rays	Compact growth
	Ferrovia spur	1992	X-rays	Dwarfness
Pear	Fuxiangyanghongdli	1983	γ-rays	Eating, cooking quality
Almond	Supernova	1987	γ-rays	Late maturity
Fig	Bol	1979	γ-rays	Not specified
Banana	Novaria	1993	γ-rays	Earliness
	Al-beely	2007	γ-rays	High yield
Japanese pear	Gold Nijisseiki	1993	γ-rays	Disease resistance
Papaya	PusaNanha	1986	γ-rays	Dwarfness
Plum	Spurdente-Ferco	1988	γ-rays	Earliness
Pomegranate	Karabakh	1979	γ-rays	--
Sea buckthorn	zyriank			

Other important varieties developed through mutation breeding

Fruit crop	Variety	Parents	Nature of mutation
Mango	Rosica	Rosa-do-delca (Peru)	Natural
	Davis Haden	Haden	Natural
Grape	Marvel Seedless	Delight	Induced
Banana	High Gate	Gros Michel	Natural
	Motta Poovan	Poovan	Natural
	Krishna Vazahi	Virupakshi	Natural
Orange	Washington Novel	Navel Orange	Natural
Grape fruit	Foster	Walter	Natural
	Red Blush	Thompson	Natural
	Thompson	Marsh Seedless	Natural
	Star Ruby	Hudson	Induced

commonly encompass better yield per crop, resistance to diseases, better nice of the crop, and quicker ripening. The advance trials of genetic mutation began in the 1930s, and now this technique of the usage of radiation to stimulate mutations in plant life has been extensively used. Radiation-prompted mutation technologies have grown to be a massive part of plant breeding methods. Here are some important cultivars and verities which had been released from various research stations with specific quality characters [4].

3. CONTROLLING PESTS AND DISEASES

Nuclear technology has been playing a crucial role in enhancing crop production by controlling pests and diseases, which typically destroy more than a third of crops before and after harvesting. Radioisotope techniques are widely used in the place of toxic chemicals in pest control. The sterile insect technique (SIT) is the most commonly used method, which involves sterilizing male insects in a laboratory using gamma radiation and releasing them into the wild. When these sterile insects mate, no offspring are produced, which helps to reduce the insect population and eventually suppress its growth. SIT has been successfully used to eliminate the Medfly, which poses a threat to around 250 species of horticultural products in some parts of the US, Chile, and Mexico. Furthermore, radioisotopes have been used in developing disease-resistant plants and animals, making them more immune to pest attacks and diseases, similar to breeding new seed varieties [5].

4. SIT (STERILE INSECT TECHNIQUE)

There are concerns that the continued use of pesticides has a negative impact on the environment and leads to the development of pesticide resistance in many insect species [6]. Furthermore, pesticides kill not only the target species but also many other beneficial pest species that help to maintain the natural ecological balance in crop fields. A very powerful programme integrating the SIT had been installed against tropical fruit flies, a few species of tsetse flies - Glossina spp., the red bollworm *Pectinophora gossypiella* (Saunders), and the codling moth *Cydia pomonella* (L.). Development of the SIT to be used against the boll weevil *Anthonomus grandis, grandis Boheman* and the gypsy moth *Lymantria dispar* (L.) has ended. However, it's miles in development for sweet potato weevil species, *Cylas formicarius* (F.) and *Euscepes postfasciatus* (Fairmaire), the fake codling moth *Cryptophlebia leucotreta* (Meyrick), the carob moth Ectomyelois ceratoniae (Zeller), the cactus moth *Cactoblastis cactorum* (Berg), the Old World screwworm *Chrysomya bezziana* (Villeneuve), additional *Glossina spp*., different *Anastrepha spp.,* the Mexican fruit fly (*Anastrepha ludens*, Loew) was eradicated from most of northern Mexico. Fruit fly species, inclusive of Mediterranean fruit fly (*Ceratitis capitata*), Caribbean fruit fly (*Anastrepha suspensa*) and Mexican fruit fly (Anastrepha ludens) in the Americas, Queensland fruit fly (*Bactrocera tryoni*) in Australia, the oriental fruit fly (*Bactrocera dorsalis*) [6].

A comprehensive review of the action of ionizing radiation on insects has been presented by Hilchey (1958). Lethal effects of X-radiation on immature stages of the oriental fruit fly and the melon fly were reported by Koidsumi [7]. Generally, dosages of 10,000 to 25,000 I' are required to prevent reproduction in insects. Indications are that these dosages may be low enough to permit the rapid or large-volume treatment that may be required for practical quarantine purposes without injurious side effects on most host material ([8]; Richardson & Balock 1959; [9]).

5. IMPROVING WATER USE EFFICIENCY

Nuclear, and particularly isotopic technology can be used to improve water use performance in horticultural contexts. Since horticulture is the primary user of freshwater resources, assisting water control can deliver an extremely useful effect on the sustainable use of freshwater resources. In particular, isotopic techniques can: 1). optimize irrigation scheduling via way of correctly tracking soil in order to decrease water losses, 2). optimize crop's water absorption cost from rainfall or irrigation, and 3). help in deciding on crops with better tolerance to drought and better crop water productivity. Optimizing irrigation scheduling is stated to affect the performance of water utilization maximum directly. So far, major advances had been made in water tracking with the use of isotopic technology. Stable isotopes may be used to asseses the abundance of oxygen, carbon, nitrogen and hydrogen in soil, water and plant helping to figure out nutrient fluxes, in the soil.

6. FOOD PRESERVATION

Food irradiation entails subjecting the meals to cautiously managed quantities of ionizing radiation, including beta debris or gamma rays, to interrupt the DNA bonds of certain pathogens. This is particularly powerful in destroying the reproductive cycle of microorganisms and pathogens. Such radiation can eliminate undesirable organisms and specific, non-spore-forming pathogenic microorganisms including *salmonella*. It also can intrude with a physiological process including sprouting in potatoes or onions. Thus, the shelf life of many ingredients may be prolonged appreciably, and meals-born ailment organisms including E-coli (0157:H7) may be dramatically reduced. The beta rays are produced via way of means of accelerators while the gamma rays are typically produced through the radioactive decay of cobalt-60. X-rays also can be efficiently used. They are typically produced by means of accelerators wherein the beta rays are directed onto a goal cloth including tungsten that converts the power into x-rays [10-15].

7. CONCLUSION

In conclusion, nuclear technology has proven to be a valuable tool for improving agricultural productivity by enhancing crop yields, controlling pests and diseases, and managing water usage. The use of physical mutagens, including ionizing and non-ionizing radiation, has facilitated the induction of beneficial mutations in crops, leading to the development of new seed varieties with improved traits. Additionally, food irradiation has been shown to be an effective method for preserving food by breaking down DNA bonds of harmful pathogens. The utilization of radioisotopes in plant growth and nutrient uptake studies has also contributed to the development of horticultural practices. Overall, nuclear technology has played an important role in addressing challenges in Horticulture and has significant potential to contribute to global food security.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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