Biological effects of radiation on crop genetics in Iraq

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Abstract. This study explores the biological and genetic impacts of radiation-based techniques applied to agricultural development in Iraq. Emphasis is placed on the use of ionizing radiation for inducing genetic mutations, improving crop traits, and enhancing plant resistance to environmental stresses. Recent experimental results from Iraqi research centers are analyzed within the framework of international cooperation and mutation breeding programs supported by the International Atomic Energy Agency (IAEA). Radiation exposure at controlled doses has been shown to generate beneficial heritable variations in several crop species, contributing to higher yield potential and improved stress tolerance. The study discusses the underlying biological mechanisms of radiation-induced mutagenesis, including DNA alteration, repair pathways, and gene expression modulation. Findings highlight the importance of integrating radiation biology with modern biotechnological approaches to accelerate sustainable crop improvement and strengthen food security under Iraq's climatic and ecological conditions.

1 Introduction

The use of ionizing radiation in agriculture represents one of the most peaceful and productive applications of nuclear capabilities. Globally, radiation technologies serve multiple agricultural purposes: inducing genetic mutations in crops, sterilizing pests, disinfecting food, and monitoring environmental radioactivity. Iraq's agricultural sector faces specific challenges of climate variability, soil salinity, pest outbreaks, and limited arable land and has increasingly turned to nuclear science for sustainable solutions.

Between 2020 and 2024, Iraq engaged in several international programs supporting the safe and peaceful use of nuclear technologies, including the IAEA's Atoms4Food initiative and the 2024–2029 technical cooperation agreement emphasizing agricultural and environmental applications (IAEA, 2024b). In parallel, Iraqi universities and research institutions conducted studies quantifying radioactivity in fertilizers, soil, and food, helping establish national baselines for radiological safety [1-3]. This paper shows Iraq's progress in

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applying radiation technology to agriculture between 2020 and 2024, emphasizing on mutation breeding and genetic improvement techniques, and analyzing scientific developments, policy frameworks and prospects for sustainable implementation as well.

1.1 Applications of Radiation in Agriculture: Mutation Breeding and Genetic Improvement

Mutation breeding uses gamma rays or X-rays to induce beneficial mutations in crop plants. The method has been employed worldwide to develop more than 3,300 officially released mutant varieties, improving yield, disease resistance, and abiotic stress tolerance [4]. In Iraq, research institutions have initiated small-scale mutation programs, supported by IAEA and regional centers, to enhance the genetic diversity of wheat, barley, and legumes. Table 1 summarizes the potential crop targets and outcomes of mutation breeding in Iraq.

Table 1. Mutation Breeding Applications in Iraq (2020–2024)

Crop	***Target Traits***	***Radiation Source***	***Current Status***	***Supporting Institution***
Wheat	Drought tolerance	Gamma (Co-60)	Pilot trials	Atomic Energy Directorate, Baghdad
Barley	Salinity tolerance	Gamma	Laboratory phase	University of Basra
Lentil	Early maturity	X-ray	In vitro studies	University of Mosul

1.2 Mutation Breeding and Genetic Improvement of Crops in Iraq

Mutation breeding — the deliberate induction of genetic variation by physical (gamma, X-ray) or chemical mutagens — has been actively used in Iraq at the university and research-center level during 2020–2024. Work has been driven by small- and medium-scale experiments (seed irradiation, molecular screening of mutant generations), increasing use of molecular markers for mutant detection, and strengthened links to international technical cooperation (IAEA) and regional academic networks that provide training and methodological guidance. The IAEA continues to promote mutation breeding as a cost-effective method for crop improvement and provides technical resources and coordination (mutation breeding overview). [1]

2 Materials and methods

2.1 Radiation sources and dosing regimes

Most Iraqi experimental programs used gamma irradiation (Cobalt-60 source) applied to dry seed lots. Studies commonly explored a broad dose range (e.g., 0–400 Gy) to establish LD50/Dq (dose producing ~50% lethality or biological response) and identify low doses that increase desirable variability without excessive sterility. Published local protocols report dose series including 0, 25, 50, 100, 150, 300 and 400 Gy for fenugreek and similar ranges for other species. This stepwise screening is consistent with best practice in mutation breeding [5].

2.2 Generational advancement and selection

Irradiated seed (M0) are grown to produce M1 plants; observations (sterility, vigor, phenotypic abnormalities) guide dose selection. Desirable M1 plants are selfed to produce M2, which is where recessive and stable mutants are most frequently identified. Several Iraqi reports document work through M2 and M3 generations for fenugreek and other crops, with phenotypic and biochemical screening (growth, yield components, phytochemical content) performed on these generations [6].

2.3 Molecular marker screening

Iraqi groups have combined classical phenotypic screening with molecular marker techniques — RAPD, ISSR, CDDP, and other marker systems — to detect induced polymorphisms and to characterize mutant lines. Reported marker results show high polymorphism rates in irradiated populations (for example, fenugreek RAPD/ISSR studies reported high polymorphism and unique fingerprints among dose treatments). Molecular screening accelerates confirmation that observed phenotypes correspond to underlying genomic changes [5,6].

3 Results and discussion

3.1 Fenugreek (Trigonella foenum-graecum)

Fenugreek seeds have been treated with gamma doses from 0 up to 400 Gy. Using RAPD and ISSR markers researchers reported clear treatment-specific molecular fingerprints; one reported a highest polymorphism value of ≈90.9% across primers and identified dose ranges (25–150 Gy) producing useful variation without severe lethality. Lower-to-moderate doses (e.g., 25–150 Gy) typically improved vegetative traits and yielded distinct molecular profiles in M2/M3 generations, while higher doses (≥300 Gy) caused strong deleterious effects (reduced germination or sterility) [7-11].

3.2 Fenugreek (phytochemical/genetic outcomes)

Controlled comparisons of gamma and chemical mutagens (EMS) found that low gamma doses (e.g., ~100 Gy) and low EMS concentrations positively affected certain traits (e.g., seed alkaloid/trigonelline levels), while higher mutagen intensities increased mutation frequency but sometimes at a cost to agronomic performance. These results demonstrate the trade-off between mutation rate and plant viability that Iraqi programs are explicitly quantifying [7-11].

3.3 Wheat and barley genetic resources

Rather than direct large-scale release of mutation-derived cultivars between 2020–2024, Iraqi research emphasized characterization of existing germplasm using molecular markers (RAPD, ISSR, CDDP). A 2024 study of 16 durum wheat cultivars collected across Iraqi research centers showed substantial within-population genetic variability and provided molecular baselines useful for targeted mutation breeding and parent selection. These diversity studies are an important precursor to efficient mutation programs because they help breeders choose genotypes likely to yield useful mutants with desirable backgrounds. [12, 13].

4 Conclusion

Between 2020 and 2024, Iraq made measurable progress in applying radiation technologies for agricultural development. Research in mutation breeding, radiological monitoring, and food irradiation has established a foundation for future expansion. Although infrastructural, regulatory, and social challenges persist, the country's participation in international frameworks such as the IAEA's Atoms4Food initiative provides critical support for advancing nuclear agriculture safely and effectively. Strengthening research capacity, expanding monitoring programs, and promoting public understanding are essential next steps toward realizing the full potential of radiation in Iraq's agricultural transformation.

Iraqi mutation-breeding activity moved from traditional seed-irradiation trials to more integrated programs combining controlled mutagenesis, multi-generation phenotyping and molecular confirmation. Verified studies (fenugreek, wheat germplasm characterization) demonstrate both methodological rigor and clear potential for trait improvement. To reach broad agricultural impact, the next five years should focus on coordinated multi-location testing, infrastructure consolidation, and formal varietal release paths — steps that can convert the promising experimental results now documented into improved cultivars for Iraqi farmers

4.1 Challenges and Constraints

Despite progress, Iraq faces several constraints in applying radiation technologies to agriculture:

- Infrastructure gaps: Limited availability of certified irradiation facilities restricts large-scale implementation.
- Regulatory framework: The absence of comprehensive national guidelines for radiation use in agriculture slows commercialization.
- Legacy contamination: Environmental remnants of past conflicts complicate radiological mapping and monitoring.

Overcoming these obstacles requires coordinated policy action, investment in research infrastructure, and public communication strategies.

4.2 Recommendations

Expand Mutation Breeding Programs: Integrate radiation-induced mutation into Iraq's national crop improvement strategies, targeting salinity, drought, and pest resistance.

Implement a National Radiological Monitoring Network: Standardize sampling and gamma spectroscopy methods for fertilizers, soils, and foods across provinces.

Public Awareness Campaigns: Inform consumers about the safety and benefits of food irradiation through transparent labeling and education.

Sustain International Collaboration: Continue cooperation with the IAEA and FAO to access equipment, training, and research networks under Atoms4Food.

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