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Electromagnetic Radiations: Biochemical and Physiological Reponses of Plants to γ-Irradiations

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Abstract: *Irradiation has found its way into various applications in agriculture, medicine, pharmaceuticals and in other technological developments. Recent research has shown the potential application of low doses of radiation for microbial decontamination. The ecological effects of high doses of ionizing radiation as pollutants have been a thing of concern to man. However, it is beneficial when applied in low doses. Gamma radiation affects seed germination, growth, physiological parameters, reactive oxygen species and DNA integrity. The effects of γ-irradiations on plants have been influenced by several factors such as species, stage of development, genome organization and quality, dose, duration of exposure of radiation. Irradiation has been applied to mutation and molecular breeding, which make use of gamma rays to breed plants with desired trait. In this review, the effect of γ-irradiations on plants, focusing on metabolic alterations, modifications of growth and development, and changes in biochemical and physiological pathways are discussed.*

Keywords: Electromagnetic radiations; gamma rays; duration of exposure; Physiological Reponses; mutation breeding

1.Introduction

Gamma-radiation is an electromagnetic wave that results in ionizing radiation that impacts different biological macromolecules and induces variable biological effects (Reisz, *et al.*, 2014; Alshammari and Hussein, 2022). Gamma irradiation effects on seed germination, plant growth, chlorophyll content, oxidative stress, and secondary metabolite production have been reported [Wi *et al*. 2007, Moghaddam, *et al*., 2011). Physiological and biochemical traits of plants have been reported to be affected by high-dose of gamma irradiation (Marcu, *et al*. 2013, Jan, *et al*.,2012). Mutation and molecular breeding, which make use of different mutagenic agents has been very useful in breeding for desired trait in plants (Majeed *et al*.,2017). The use of mutagenic agents like gamma irradiation is reasonably economical and easy to practice as compared to other molecular techniques in mutation breeding (Thomson *et al*., 2009; Çelik and Atak, 2017). Radiation sources such as Co60 and Cs137 can release high-energy electromagnetic gamma rays and this has been effectively used to eliminate contaminating microorganisms (Silindir and Özer, 2009). This paper reviewed the effect of gamma irradiation on germination and growth, chlorophyll content, reactive O_2 species, secondary metabolite production and DNA integrity of plants

2.1. Germination and growth response of plants to radiation stress

Root and shoot lengths subjected to higher gamma irradiation doses have been reported to be reduced and these have been attributed to reduction of mitotic activity in meristematic tissues and also reduced moisture content of seedlings (Majeed *et al*., 2009). Reduced root and shoot lengths were also reported in various crops such as in cowpea (Thimmaiah, *et al.*,1998). Shoot and root fresh dry weight reduction in some crops has been reported due to increasing doses of gamma irradiation. This reduction was observed in various crops such as chickpea, (Melki and Sallami, 2008) cluster bean (Mahla *et al*.,2018), common bean (Ulukapi and Ozmen, 2018). Negative mutation, ionization of water present in cells and subsequent formation of reactive oxygen species and free radicals which can interact with other cellular molecules potentially imposing negative structural and functional changes are the causes of growth abnormalities and low germination of plants in response to higher doses of gamma irradiation (Wang *et al*., 2017). High gamma radiation doses cause physiological changes, such as a delay in seed germination and a reduction in the survival rate and plant growth, in wheat [Melki and Marouani, 2010; Pane, *et al*., 2018; Irfaq, and Nawab, 2001). Lower doses of radiation often cause germination and growth improvements in plants while higher doses result in growth abnormalities, germination retardation or even death of exposed plants (Majeed *et al*., 2016; Hong *et al*.,2017). Gamma rays at 100 Gy enhanced growth, yield characters, and certain biochemical constitutes of fenugreek (Hanafy and Akladious 2018) and wheat plants (Al-Rumaih and Al-Rumaih, 2008)**.** Ionizing radiation from 10 to 1000 Gy caused dramatic alterations in the composition of plant cells and induced cell death (Caplin and Willey,2018).

2.2. Chlorophyll response to radiation stress

High gamma radiation doses reduce photosynthetic activity, ultimately decreasing the chlorophyll content and plant growth [Marcu, *et al*.2013; Kim, *et al*., 2015). Inhibitory effect of gamma irradiation on chlorophyll biosynthesis and degradation is the cause of reduced chlorophyll 'a' and 'b' as reported in groundnut. Sreedhar *et al*., 2013 Yasmin *et al.*, 2019). Carotenoids contents play a vital role to prevent photodamage caused by gamma radiation and free radical scavenging (Fukuzawa *et al*., 1998). Carotenoids contents directly react with lipid peroxidation product and terminate chain reaction and also react with singlet oxygen hence reveal the protective nature of carotenoids against reactive oxygen stress induced by gamma irradiation on photosynthetic pigments reported in wheat leaves (Loggini *et al.,* 1999). Lower gamma radiation dose was insensitive to chlorophyll but carotenoid content increased at higher doses and dose dependent effect was noticed in red pepper (Kim *et al*., 2004).

2.2. Free radical response to radiation stress

Hydrogen peroxide (H_2O_2), superoxide radicals (O_2-), and hydroxyl radicals (OH) were generated as result of radiation leading to oxidative stress (Suzuki *et al*. 2012). In plants, gamma radiation induces oxidative stress and causes cellular damage and destroys almost all the functional and structural molecules such as lipids, proteins and nucleic acids. Free radicals act as intermediates for most of the metabolic process. Gamma radiation enhances the production of primary free radicals in plants Lee, *et al*. (2005).

2.3. Biochemical and physiological responses of plants to radiation

Gamma irradiation have been reported to affect plant growth and development by inducing cytological, genetical, biochemical, physiological and morphogenetic changes in cells and tissues (Jan *et al*., 2010). High dosages of gamma rays disturb the hormone balance, leaf gas-exchange, water exchange and enzyme activity in plants (Stoeva, 2002). The total protein and carbohydrate contents in germinating seed decreased with increasingly higher dosage of g-irradiation due to higher metabolic activities and hydrolyzing enzyme activity in germinating seed (Maity *et al.* 2004). Protein are broken and more amino acids are released when seeds are irradiated (Maity *et al*., 2004; Kiong *et al.* 2008). Four phenolic acids (gallic acid, 4-hydroxybenzoic acid, p-coumaric acid, and caffeic acid) were identified and five flavonoids were detected in hydrolyzed samples ((+)-cat- echin, (-)-epicatechin, kaempferol-3-glucoside, quercetin-3-glucoside, and quercetin-3-galactoside) in strawberry exposed to gamma irradiation (Breitfellner *et al*., 2002).

Behgar, *et al.* (2011) observed that the alterations in the effect of gamma radiation on total phenolic compound may be due to the higher extractability of these compounds in irradiated products. Irradiation is able to break the chemical bonds of bioactive compounds, releasing soluble phenolic with low molecular weight and increasing these compounds with antioxidant potential (Adamo *et al*., 2004). Also, gamma radiation at 200 Gy enhanced flavonoid compounds in 37 wheat lines (Han *et al*.,2020).

2.4. Response of plants DNA to radiation

The expression of antioxidant-related and DNA-repair-related genes in wheat has been showed by Hong *et al.* (2022) to decreased significantly under long-term gamma-ray exposure. Long-term exposure caused higher radio sensitivity than short-term exposure (Hong *et al.,* 2022). Radiation doses of 10, 15, 20, 25 and 30 kR caused different types of chromosomal anomalies in wheat plants, which increased with the increasing intensity of gamma radiation (Verma and Khah, 2016). Radiation can affect the integrity of genetic information and impair genomic stability by inducing DNA damage.

3. Conclusion

Studies have showed that lower doses of gamma irradiation stimulate the growth of plant by either direct genome modifications or regulation of cellular process which could lead efficient cell division, high photosynthesis rate and improved capacity of plants to cope with environmental stresses. However, higher doses cause alteration in DNA, production of free radicals and reactive oxygen species which can influence germination and growth in a negative manner.

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