



Potential of gamma rays to improve grain yield and nutritional quality of pearl millet (*Pennisetum glaucum* L.): A review

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ABSTRACT

Pearl millet is an important food and feed crop mostly cultivated in the semi-arid region of the world. Ionizing radiation has been widely used as a tool in plant breeding programs. Similar to other techniques of crop improvement, irradiation can induce alterations that can modify the chemical composition and the nutritional value of food crops. These changes depend on the irradiation dose and the crop species and give plant breeders the opportunity to select induced desirable mutants. In this paper, we discuss the usefulness of gamma radiation in achieving improvements in the grain yield and nutritional quality of pearl millet.

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Introduction

Induced mutation is one of the best alternatives for the improvement of crops as it can help to regenerate and restore the variability, which is generally lost in the process of adaptation to various stresses. Genetic variability is the source from which plant breeders produce new and important cultivars. This is achieved through recombination and independent assortment of favourable alleles to produce new and unique individuals from which to select and produce the lines that serve as new cultivars.

Ionizing radiations are the most commonly used among the physical mutagens [25]. These form part of the electromagnetic (EM) spectrum that are capable of dislodging electrons from the nuclear orbits of the atoms they impact upon on account of their relatively high energy levels. The impacted atoms therefore become ions hence the term ionizing radiation. These ionizing components of the EM include cosmic, gamma (γ) and X-rays. Ultra violet (UV) light, though non-ionizing, is capable of some level of tissue penetrability and has been used in inducing mutations as well.

Millets are extremely important in the semi-arid and sub-humid zones of Africa as staples and ethno-botanical crops. It is produced on 18.5 million ha and yields about 11.4 million tons, mainly at subsistence level in 28 countries across Africa [34, 29]. Millets are rich sources of human and livestock nutrition in developing countries [28]. They contain high amounts of vitamin, calcium, iron, potassium, magnesium, and zinc [23] and its protein content is comparable to that of wheat and maize. The grains of most millets do not contain gluten [23], the substance that causes celiac disease or other forms of allergies.

Despite the immense contribution of millet as a source of food and feed in the arid and semi-arid parts of Africa, its yield is far below optimum. For the last 35 years in all of Africa, the area planted to millets has increased by 50% but yields, averaging 620 kg/ha have not shown any significant change [4]. This is attributed to yield reducing factors such as genetically low yielding landraces, striga, pests and diseases. These yield

reducing factors can however be regulated by creating varieties that selectively resist their impact.

Mutation breeding is relatively a quicker method for improvement of crops [12] relative to conventional breeding which takes 10 to 15 years of experimentation [35]. A number of useful mutants have been induced for various plant characters in crops through treatment with physical and chemical mutagens [32, 6].

Mutation breeding

Plant breeding requires genetic variation of useful traits for crop improvement and selection. Often, however, desired variation is lacking. Mutagenic agents, such as radiation and certain chemicals, then can be used to induce mutations and generate genetic variations from which desired mutants may be selected. Mutation induction has become a proven way of creating variation within a crop variety.

It offers the possibility of inducing desired attributes that either cannot be found in nature or have been lost during evolution [32]. When no gene, or genes, for resistance to a particular disease, or for tolerance to stress or improvement of some economic traits, can be found in the available gene pool, plant breeders have no alternative but to attempt mutation induction.

Experimental mutagenesis is an important source of producing mutation in higher frequencies in cultivated crops. Excellent source of valuable materials for breeding work can be provided by establishing extensive collection of mutations based on productive characters. The simultaneous realization of different breeding objectives could be made possible through induced mutagenesis.

Induced mutation

Mutations have been induced to broaden the genetic diversity for enhancing crop productivity in both seed and vegetatively propagated crops. Mutations are induced by physical (exposure to gamma radiation, high and low energy beams, etc.) and Chemicals (ethyl methane sulfonate, (EMS),

etc.) mutagen treatment of both seed and vegetatively propagated crops.

The stability of the genetic composition of organisms is not absolute and can therefore be altered under the influence of certain physical and chemical factors [6]. Otherwise evolution of new varieties will be impossible. Sometimes changes occur in chromosomes, triggered by external or internal factors. They may affect the chemical structure at one or several gene loci, change their alteration in the chromosome, or cause other deviations [7].

The efficiency of plant breeding programme is determined by the amount of genetic variability available in the segregating generation. Experimental mutagenesis is an important source of mutation in higher frequencies in cultivated crops. Excellent source of valuable materials for breeding work can be provided by establishing extensive collection of mutations based on productive characters. Mutation breeding is an effective tool for generating variability in the existing varieties prior to selection based on desirable traits [16].

Genetic variability is the most essential prerequisite for any successful crop improvement programmes [41]. In plant improvement, the irradiation of seeds may cause genetic, variability that enable plant breeders to select new genotypes with improved characteristics such as precocity, salinity tolerance, grain yield and quality [3].

It has been demonstrated by many workers that genetic variability for several desired characters can be induced successfully in plant breeding programmes. Crop improvement programmes in developing countries has yielded great success through induced mutagenesis since the 1930s [1].

Since 1928, several breeding works use radiation very extensively for inducing mutations in crop plants. Radiation might be ionizing and non-ionizing. A gamma ray is a pack of electromagnetic energy photon. Gamma photons are the most energetic photons in the electromagnetic spectrum. Gamma rays are emitted from the nucleus of some unstable atoms and can induce beneficial as well as deleterious effects on crops. It is therefore imperative to determine the optimum dose for improvement of specific traits of crop plants [14]. For the purposes of crop improvement, the aim is to obtain a reasonable number of desired mutations for a trait of interest while inflicting the least unintended disruption to the genotypic integrity of the crop [3]. According to [24], the optimum dosage is the one that results in reduction of 50% in parameters measured in the first generation mutant (M1) seedlings compared to the parent material.

Mutation breeding in seeded crops

Gamma irradiation of seed has been utilised successfully in crop improvement programs to create genetic variability from which genotypes with improved characters are selected [3]. Chimerism, a situation whereby tissues of an individual plant contains different genotypes that exist side by side, is an issue with mutagenic treatment of seeds [41]. Chimerism results because seeds are multi-cellular and thus the individual cells differ in the extent to which they harbour the mutagen they are exposed to. This is however significantly dissociated in one to two generations of selfing (M2 to M3) [41].

Action of gamma ionization on biological materials

Gamma particles are photons produced in a radioactive decay chain when a massive nucleus produced by fission is released from the excited state in which it was first formed towards its lowest energy or ground-state configuration. Gamma rays belong to the ionizing radiation, which constitute the most commonly used physical mutagens [25] and may act

directly on the cellular component molecules [21] or indirectly on water molecules, causing water-derived radicals. Radicals react with each other or nearby unchanged molecules in a very short time, resulting in breakage of chemical bonds or oxidation of the affected molecules. These radicals have the potential to damage or modify important components of plant cells differentially based on the dosage of irradiation [3].

The major effect of gamma rays in cells is DNA breaks [10]. Since DNA consists of a pair of complementary double strands, breaks of either a single strand or both strands can occur. However, the latter is believed to be much more important biologically. Because of the double-stranded structure of the DNA, most single-strand breaks can be repaired normally; with the intact strand serving as a template for repair of its damaged, opposite strand. The repairing process is more tedious and erroneous in double-strand breaks. These erroneous repairs induces mutations with consequent effects including changes in cellular plant structure and metabolisms such as dilation of thylakoid membranes, changes in photosynthetic process, modulation of the antioxidative system and accumulation of phenolic compounds [18, 43].

Effect of gamma irradiation on morphological and economic characters

Nuclear techniques have proven its usefulness in modern agriculture in several ways [2, 10,30]. Gamma rays have been used to irradiate a wide range of plant materials, like seeds, whole plants, plant parts, flowers, anthers, pollen grains and single cell cultures or protoplasts. Gamma irradiation has an intensive effect on the growth and development of plants by inducing genetic, cytological, biochemical, physiological and morphogenetic modifications in cells and tissues depending on the irradiation dosage [9]. They can be useful for the alteration of physiological characters [20]. The uniqueness of these rays is due to their high penetration power and accounts for their wider application for the improvement of various plant species relative to other ionizing radiations [26], having the energy level from around 10 kilo electron volts (keV) to several hundred keV. The lower doses of the mutagenic treatments could enhance the biochemical components, which are used for improved economic characters [27].

The effectiveness of radiation to induce mutations is assessed based on a number of radiobiological parameters. Mutagenic radiations are a useful tool to all breeding programs associated with flowering crops [22]. The effect of gamma rays on the trait of crop plants is dependent on such factors as crop species and the irradiation dosage [2]. Changes, include metabolism and cellular changes in plants, modulation of the antioxidative system, photosynthetic alterations and phenolic compounds accumulation [18, 43].

Seed irradiation during the pre-sowing is one of the most effective methods to improve plant production, yield components and chemical composition [37]. Induced mutations have been used for the improvement of major crops such as wheat (*Triticum* spp.), rice (*Oryza sativa*), barley (*Hordeum vulgare*), cotton (*Gossypium hirsutum*), and chickpea (*Cicer arietinum*) all propagated by seed [1]. Success has been achieved in numerous crops by several scientists through induction of mutagenesis. Improved barley variety with early maturity, high protein contents and stiff straw has been developed by mutation breeding techniques [15]. [16] collected three high grain yielding and early maturing mutants by treating seeds of *Brassica juncea* L. cv. S-9 with gamma rays (750-1000 KGy) and EMS. [33] discussed the findings related to the different researches with gamma irradiation in wheat and they

reported that the doses above 5 kGy created a bad influence on bread quality. [8] studied the effects of gamma rays on tillers number and plant height in six cultivars of wheat. The results showed that these cultivars differed significantly for both the characters. [10] observed that 40 Krad dose caused maximum reduction in various genetic parameters of wheat and triticale.

Mutation induction for improvement in quality and nutrition of crops

Besides increase in yield of a crop, quality and nutrition components are equally important in human diet. There is a necessity to enhance mineral elements and amino acids essential for human and animals, alter the protein and fatty acids profiles for nutritional and health purposes, change the physicochemical properties of starch for different end uses, enhance the phyto-nutrients in fruits and reduce the anti-nutritional factors in staple foods. Induced mutations could play an important role in inducing changes for enhancing nutritional quality in crop plants. For instance, [13], through induced mutagenesis produced new strains of cereals with higher concentrations of micronutrients and improvement of their bioavailability by reduction in the concentration of phytic acid.

Several mutant genes have been successfully introduced into commercial crop varieties that significantly enhance the nutritional value of crops like maize, barley, soybean, and sunflower. [31], identified three major micronutrient deficiencies in humans which include vitamin A deficiency, iron deficiency and iodine deficiency. Micronutrient deficiency of Zn has also received global attention [11]. In addition, improving the content of essential amino acids in important staple foods, such as rice, has gained interest [42]. [36], concluded that irradiation with low doses of 5 to 50 Gy were the safety doses that can be employed as a perfect tool for pea seed preservation and for stimulating seed germination, growth and metabolic processes as well as increasing seed yield and the nutritional value of seeds.

An adequate concentration of micronutrients seems to be essentially required in major staple crops if these crops are addressed to provide a sustainable solution to the problem of malnutrition [30]. This holds true for cereals since majority of the population in the developing world depend on cereal based food intake.

Conventionally, nutrient content of crops can be improved by using field fortification strategies, to enhance the micronutrient and trace element content of crops by applying enriched fertilizers to the soil. Biotechnological tools have generated new opportunities to improve the amount and availability of nutrients in plant crops. These include simple plant selection for varieties with high nutrient concentration in the seeds, cross-breeding for incorporating a desired trait within a plant, and genetic engineering to manipulate the nutrient content of the plant [19].

Agricultural biodiversity is essential both in terms of food and nutritional security. Global food security depends mostly on a handful of cultivated species and more than 50% of the daily requirements of proteins and calories is derived from three major crops viz., wheat, maize and rice [5].

In contrast, the availability of orphan- or understudied-crops as the major staple food crops in many developing countries has contributed significantly. Some examples include, cereals (e.g. millet, tef, fonio), legumes (cowpea, bambara groundnut, grass pea), and root crops (cassava, yam, enset). Orphan crops are in general more adapted to the extreme soil and climatic conditions prevalent in Africa than the major crops of the world. Minor millets, which are high in nutrients such as calcium and iron, are

grown primarily in hilly, arid areas where, because of their high tolerance to drought, are often more productive than other grains [40, 41]. However, due to lack of genetic improvement, orphan crops produce inferior yield in terms of both quality and quantity.

Crops improved through experimental mutagenesis

Successful improvements in crop characteristics have been achieved through mutagenic inductions. [15], through experimental mutagenesis have developed a barley variety with improved characteristics; high yielding barley, early maturing, high protein contents and stiff. [7], obtained agronomically and nutritionally superior horsegram (*Macrotyloma uniflorum* (Lam.) Verdc) cultivar, Dapoli Kulthi-1 mutants, by mutation induction with gamma radiation. [17] obtained three mutants of *Brassica juncea* L. cv. S-9 with improved yielding ability and earliness to maturity by treating seeds with gamma rays (750-1000KGy) and EMS. [38] developed a new oil seed *Brassica napus* L. cv. ABASIN-95 by induced mutation. They subjected *B. napus* L. cv. Tower seeds to 1.0, 1.2 and 1.4 KGy gamma rays and consequently obtained a mutant that was high yielding, resistant to *Alternaria* blight and white rust.

Conclusion

Yield and nutritional enhancement is integral to food security. The forgoing has indicated that gamma rays can successfully be used to improve yield and nutritional qualities in cereals. Across sub-Saharan Africa, where pearl millet constitutes a bulk of feed consumption, the use of gamma rays to improve yield and nutritional quality need be extensively explored. Gamma irradiation induces genetic alterations that can modify the chemical composition and nutritive value of the crop. Induced mutations are therefore significant as improved crops can be isolated and selected for enhanced yield and nutrition quality.

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