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Review: Utilization of Nuclear Technology in Agriculture and Food Sector

Retno Dwi Astuti[1], Nita Handayani[2]
[1,2]Physics Department, Faculty of Science and Technology, UIN Sunan Kalijaga,
Jl. Marsda Adisucipto, Yogyakarta, Indonesia 55281.
[1]Email: retno.dwia15@gmail.com

Abstract. The development of nuclear technology is beneficial for many sectors including farming, health, industry, hydrology, archeology, mining, and agriculture and food. One of the interesting thing to be discussed is utilization of nuclear technology in agriculture and food sector. These sectors are crucial and closely related to the fulfillment of human life needs. This article discussed the use of nuclear technology in agriculture and food. The implementation of nuclear technology in agriculture and food could be found in several things, those are in mutations for plant breeding using gamma irradiation technique, fertilization efficiency using tracer technique, plant pests control using the sterile insect technique (*TSM*), and food or crops preservation using irradiation technique. By maximizing the utilization of nuclear technology, it is expected that it can increase productivity in the agriculture and food sectors.

Keywords: Agriculture, food, irradiation, nuclear technology

INTRODUCTION

Technology is one of the results of civilization emerged from human thoughts to make it easier to solve everyday life problems. One of God's great gifts and should be grateful is nuclear technology. This gift has been and will always be used maximally for goodness in various aspects of life.

Nuclear technology was discovered by Henri Becquerel in 1896 through conducting research on the phenomenon of phosphorescence in uranium salts that was eventually called radioactivity. Together with Piere and Marie Curie, Becquerel started studying this phenomenon, and in 1898 Marie Curie discovered the radioactive elements; radium and polonium. In the process, they isolated the radioactive element radium. Radioactive materials produce radiation emitted in the form of electromagnetic waves and particles called alpha, beta, and gamma rays. The three forms of radiation discovered by Becquerel and Curie include alpha decay occurred when an atomic nucleus releases two protons and two neutrons (equivalent with a helium atomic nucleus), beta decay that is a high-energy electron, and gamma decay that is an electro-magnetic wave at the very high frequency and energy. The three types of radiation occur naturally (Kisnanto and Syaifudin 2016).

The use of nuclear technology can be seen in its implementations in various fields such as farming, health, industry, hydrology, archeology, mining, and agriculture and food. One of the interesting thing to be discussed is implementation of nuclear technology in agriculture and food sector. These fields are very crucial and closely related to the fulfillment of human life needs. To preserve human survival, good quality food sources are needed. The agricultural industry in Indonesia might grow and develop if agricultural products can be increased both in quantity and quality. As an agricultural country with extensive and fertile land, Indonesia has the potential and great opportunity to increase its agricultural products so that it can compete in the global market (Soeranto 2003). In its development, nuclear technology has a significant role in this field. Therefore, this article reviewed the implementation of nuclear technology in agriculture and food sector.

MATERIALS AND METHODS

This article was a paper review using the library research method. The study was carried out from various sources relevant to the topic raised by the author. The results were presented in narrative form.

RESULTS AND DISCUSSION

The use of nuclear technology in agriculture and food consists of four aspects; plant breeding, fertilization efficiency, plant pests control, and food or crop preservation (Kisnanto and Syaifudin 2016).

1. Plant Breeding using Gamma Irradiation Technique

The obtaining of superior seeds needs to be done as an effort to increase population diversity in the hope that new characters can be selected for various purposes of breeding programs, such as tolerance to various biotic and abiotic stresses, certain nutritional quality characters, and so on by irradiation. One of the ways to increase the diversity of the basic population is through physical mutation induction using gamma ray irradiation. Mutations can be referred to as changes in genetic material at the level of the genome, chromosomes and DNA or genes that cause genetic diversity. The success of irradiation efforts to increase population diversity is largely determined by the radiosensitivity of the irradiated genotype. The level of plant sensitivity greatly varies between plant types and between genotypes. Radiosensitivity can be measured based on the LD_{50} value (Lethal Dose 50) that is the dose causing the death of 50% of the plant population (Herison et al. 2008).

The basic principle is that the seeds are irradiated at a certain dose. The amount of irradiation dose given is a function of time and dose rate owned by the gamma chamber during treatment, with the formula: dose = time x dose rate. After irradiation, the seeds are planted and observed in the field. In mutation induction, several studies have shown that the optimum dose that can produce the most mutants usually occurs around the LD_{50}. The mutation induction carried out by gamma ray irradiation of the seeds at a dose around the LD_{50} resulted in plants having different characters from their parents (M_0), thus, increasing the population diversity in each seed.

Mutation induction using gamma irradiation has been carried out in maize. The response pattern of early seed growth and the radiosensitivity of maize lines to gamma ray irradiation are varied between lines. The $LD5_0$ value of the lines tested ranged from 97 Gy to 424 Gy. The diversity of characters in the form of amount of leaf, leaf length, and leaf width increased between 30-80%, while plant height increased between 250-1300% due to irradiation at LD_{50} (Herison et al. 2008).

One of the gamma irradiation techniques for mutation breeding has been carried out on the common bean (*Phaseolus vulgaris* L.). The difference in gamma irradiation dose (^{60}Co) affected seed growth, plant survival, also plant morphology such as shoot length, root length, shoot weight, root weight, stem diameter, leaf width, leaf length, and chlorophyll index in M_1 plants (Ulukapi and Ozmen 2018) .

2. Fertilization Efficiency using Tracer Technique

The efficiency of fertilizing plants using radioisotope tracer techniques is one of the potentials towards a sustainable agricultural system. Tracer techniques can be used to investigate the relationship between soil and plants, determine the optimal conditions for fertilizer use (fertilization time, active root pattern, type, and dose of fertilizer), investigate the process of decomposition and mineralization of organic matter, and analyze the photosynthetic process of plants, either by direct or indirect methods. The more precise timing of fertilization can be determined using this tracer technique, so that the optimization of fertilization can be achieved (Sutapa et al. 2016).

Tracer technique is a technique used with the aim to obtaining behavioral information from an object by marking the object with a certain material. The basic application of the tracer technique using radioisotopes is the radioactive exposure activity of each element used. Several radioisotopes are ^{14}C, ^{45}Ca, ^{32}P, and ^{3}H. Then, several tools that can be used to measure the exposure activity are the Liquid Scintilation Counter (LSC) and the Gamma Counter (Nurfaizah et al. 2016).

The measurement of efficient time to fertilize plants can be determined using a radioactive tracer method by applying ^{32}P isotope that is scattered to the plants. ^{32}P isotope is obtained from KH_2PO_4 solution or H_3PO_4 solution (Sutapa et al. 2016, Nurfaizah et al. 2016). The ^{32}P radioisotope bound in superphosphate compounds (fertilizers) has the same chemical traits as the ^{30}P isotope contained in the soil. Thus, in soil, these two isotopes have the same behavior. The difference is that ^{32}P emits detectable β radiation, whereas ^{30}P does not emit radiation. Thus, P from soil and P from fertilizers can be easily distinguished. The count rate of β radiation emitted by ^{32}P can be calculated and compared with the count rate obtained from standard solutions, so that the levels of ^{32}P radioisotope or fertilizer absorbed by plants will be known (Kusuma and Wijatna 2008).

Radionuclides are determined based on the data from the count results that are then calculated using the equation:

$$\mathrm{dps} = \frac{\mathrm{cps}}{\eta} \tag{1}$$

where *dps* is the disintegrity per second, *cps* is the count per second, and η is the efficiency of the counting device.
To determine the concentration of radioactive substances in plants, the equation is:

$$\mathrm{X} = \frac{\mathrm{A}}{\mathrm{m}} \tag{2}$$

where *X* is the radioactivity rate of the detected plant part sample (Bq/g), *A* is the absorbed radioisotope activity (Bq), and *m* is the mass of the detected plant part (Sutapa et al. 2016, Nurfaizah et al. 2016).

3. Plant Pest Control using Sterile Insect Technique

In the agricultural sector, one of the important factors in the food-crop production process is crop protection against pests, because insect pests often suddenly attack. Thus, they can thwart the crops and damage dry agricultural products stored in warehouses. One of the way to control pests is using the Sterile Insect Technique. There are 2 types of sterile insect technique (Sutrisno 2006):

1. Methods including mass breeding, insect sterilization in the laboratory, and releasing sterile insects into the field. If sterile insects are released in an insect population, the ability of the population to reproduce will decrease according to the ratio between the released sterile insects and the insect population in the field.
2. Direct sterilization method, where sterilization carried out directly on insects in the field.

The basic principle of sterile insect technique is to kill insects using the insects themselves (autocidal technique). This technique involves irradiating the insect colony in the laboratory with certain rays, then periodically releasing it in the field, so that the mating rate of sterile insects and fertile insects from the first generation to the next is greater and affect to decrease the percentage of insect population fertility in the field. Theoretically, in the 4th generation the fertility percentage reaches the lowest point, 0%. In other words, the number of insect populations in the 5th generation is zero.

The factors that influence the process of sterility in insects are the occurrence of sperm inactivation, dominant lethal mutations, *aspermia* and the inability to copulate with female or male insects. Radiation can reduce egg production because the oogenesis process does not occur, so that *oogenia* or eggs are not formed. *Aspermia* could cause sterility because radiation destroys spermatogenesis and prevents sperm from forming. Inactivation sperm could also cause sterility because the sperm is unable to move to fertilize an egg. In this case, if the radiation is low enough, sperm is still formed or the spermatogenesis process is not disturbed, but the sperm formed is weak or inactive. Another factor that causes sterility is the inability to copulate. In this case, the radiation damages the somatic cells of the internal genitalia line, so that fertilization of the egg does not occur (Sutrisno 2006).

4. Food and Agricultural Products Preservation using Irradiation Technique

Food or crops preservation is also important for maintaining the quality of agricultural products. Foodstuff preservation is known as an effort made to extend the foodstuff shelf life, so that foodstuff can be consumed for a longer time. The irradiation method is a type of food preservation. Food irradiation is a food preservation technique using controlled ionization radiation to kill insects, mold, bacteria, and parasites or to maintain the freshness of food. Irradiation that is carried out aims to inhibit or prevent damage to foodstuffs, maintain material quality, avoid poisoning, and facilitate handling and storage (Safitri and Fitri 2010).

The type of food irradiation that can be used for foodstuff preservation is electromagnetic radiation that produces high-energy photons causing ionization and excitation of the material in its path. This type of irradiation is called ionizing radiation. Two types of ionizers commonly used for food preservation are γ rays emitted by the radionuclides Co-60 (Cobalt-60) and Cs-137 (Cesium-137), as well as the electron beam of electrically charged particles.

During the irradiation process, these foodstuff would absorb gamma ray radiation. Radiation would break the chemical bonds in the DNA of contaminated microbes or insects so that contaminated organisms were unable to repair their damaged DNA and their growth would be stunted. In the irradiation of this foodstuff, the irradiation dose was not large enough to cause the foodstuff becoming radioactive (Safitri and Fitri 2010).

Gamma irradiation technique can be applied for preservation of fresh vegetables, such as celery. When celery was cut (harvested), the cut tissue would be contaminated with various microorganisms that might cause the celery not long-lasting, such as easily withering or rotting. Gamma irradiation was utilized in order to extend shelf-life and to ensure the safety of fresh-cut celery. After a certain dose of gamma irradiation, the results showed that the number of bacteria and fungi in fresh-cut celery was decreased (Lu et al. 2005). Ionizing radiation can also be used to preserve fruits, such as kiwi. This irradiation process did not really affect the color of the fruit. This irradiation process deactivates pathogens such as *Botrytis cinerea, Diaporthe actinidiae*, and *Botryosphaeria dothidea* found in kiwifruit so that the fruit shelf life is longer (Kim and Yook 2009).

CONCLUSIONS

Nuclear technology provides a major contribution to life, including in agriculture and food sector. The utilization of nuclear technology in agriculture and food sector consists of four aspects; plant breeding, fertilization efficiency, plant pest control, and foodstuff and crop preservation. To obtain superior seeds (plant breeding), mutation can be done through gamma irradiation. For efficient fertilization, a tracer technique using radioisotopes can be used. To control plant pests, the sterile insect technique can be applied. For the foodstuff and crop preservation, gamma irradiation can be carried out. By maximizing the utilization of nuclear technology, it is expected that it can increase productivity in the agriculture and food sectors.

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