Radiosensitivity and effect of gamma ray irradiation on upland rice CV. Sidikalang

D Naibaho¹, E Purba*¹, D S Hanafiah¹ and S Hasibuan²

¹Department of Agriculture, Faculty of Agriculture, Universitas Sumatera Utara, Medan, Indonesia.
²Department of Agriculture, Faculty of Agriculture, Universitas Medan Area, Medan, Indonesia.

E-mail: *edisonpurba@usu.ac.id

Abstract. Improvement efforts to obtain high yield and adaptive varieties can be carried out through plant breeding programs. The success of irradiation in increasing population diversity is determined by plant radiosensitivity. Radiosensitivity aimed to determine a dose that caused plant death (lethal dose) or growth inhibition of 50% of the irradiated population (LD-50). The seeds of rice CV. Sidikalang was irradiated with gamma rays at doses of 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100 and 1200 Gy. The results showed that the value of Lethal Dose (LD-50) on the percentage of germination is 586.446 Gy and the gamma ray irradiation treatment gave different responses to plant height.

1. Introduction

In Indonesia, rice is the main commodity in meeting people's food needs because it is an important food crop that has become the staple food. As the population increases, the need for food is also increasing. Rice is a self-pollinating plant so that it has low genetic diversity. Sidikalang cultivar rice is a local upland rice plant of North Sumatra with several plant characteristics, namely deep age and categorized as high plant and not resistant to falling down.

Improvement efforts to obtain high yield and adaptive varieties can be carried out through plant breeding programs, one of which is mutation induction. Mutations can increase genetic diversity. There are two types of mutations, namely physical and chemical mutations, physical mutations that cause changes in chromosomes and DNA so that the physiological processes in plants become abnormal and produce new genetic variations [1].

Mutation induction can be carried out in plants and animals with chemical and physical mutagens. Physical mutagens are carried out using ionization irradiation (X rays, gamma, alpha, beta and neutrons) and UV light is irradiation without ionization [2]. Gamma rays are ionizing electromagnetic irradiation with high energy. Energy levels of gamma rays range from 10 kilo electron volts (keV) to several hundred-kilo electron volts. Gamma rays have a stronger penetrating power than other types of irradiation such as alpha and beta rays and can be ionizing the atoms of the molecule it passes through [3]. The effect of irradiation on plants can be seen from the diversity of agronomic characters of a plant. The success level of irradiation to increase population diversity was determined by plant radiosensitivity. The Radiosensitivity to provide an overview of the effects of irradiation on irradiated objects. The irradiation dose is different for each cultivar and plant variety [1].
Based on the above, it is necessary to know the correct irradiation dose for Sidikalang rice cultivar which can induce the highest genetic diversity. This research aimed to obtain the radiosensitivity level of Sidikalang rice cultivars.

2. Materials and methods

The study was conducted in Medan Timur District from September to October 2019. The research material was the Sidikalang cultivar rice seed collected from North Tapanuli. The seeds of rice CV. Sidikalang were irradiated with gamma rays from $^{60}$Co using a Gamma Cell 220 irradiator in PAIR BATAN with doses of 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100 and 1200 Gy. The number of treatment was 13 treatments with 16 replications with the number of seeds irradiated for each treatment as much as 50 g wrapped in a brown envelope per each irradiation dose and the one week after being irradiated the seed were planted in the seedling tray.

The seeds of rice CV. Sidikalang were planted in seedling trays at out room, then at 4 weeks after planting, the observation was carried out on the percentage of germination and plant height to determine the value of Lethal Dose (LD-50) used germination percentage data at 4 Week After Planting (WAP), then analysed using the Curve-fit analysis program.

3. Results and discussion

The results of the gamma ray irradiation research on Sidikalang cultivar showed that the highest germination percentage was obtained at doses of 200 Gy and 300 Gy (100%) while the lowest was at doses of 800 Gy to 1200 Gy (0%). It showed that the higher irradiation dose affected the germination process of rice seeds. This is in line with [4], at a dose of 700 Gy-1000 Gy of irradiation, the germination percentage of Mira-1 and Bestari rice seeds was inhibited. Similar to [5], who found that no germination of West Sumatra black upland rice seeds at 500 Gy.

| Irradiation Dose (Gy) | Percentage of germination (%) | Plant height (cm) |
|-----------------------|------------------------------|-------------------|
| Unirradiated          | 100                          | 60.84±0.87        |
| 100                   | 93.75                        | 58.65±1.07        |
| 200                   | 100                          | 57.21±0.84        |
| 300                   | 100                          | 57.06±0.78        |
| 400                   | 93.75                        | 45.47±1.43        |
| 500                   | 81.25                        | 37.18±0.81        |
| 600                   | 56.25                        | 32.54±0.52        |
| 700                   | 1.16                         | 1.00±0            |
| 800                   | 0                            | 0                 |
| 900                   | 0                            | 0                 |
| 1000                  | 0                            | 0                 |
| 1100                  | 0                            | 0                 |
| 1200                  | 0                            | 0                 |

The effect of increasing the dose of gamma rays affects the growth of the Sidikalang rice cultivar. The higher the irradiation dose given, the lower seed height growth (Table 1). In this case, plant growth at irradiation doses of 700 Gy to 1200 Gy at 4 WAP has decreased and suppressed plant height up to 46.51 % (Dose 600 Gy) compare to untreated plant. The decrease in plant height occurs due to an increase in the dose of irradiation which results in disruption of the cell division process as a result of DNA mutations. The inhibition of the growth rate is also closely related to the balance of plant hormones (auxin) and enzyme activity during the germination process [6].
In this study where in some plants change leaf colour from green to whitish yellow (Figure 1). Rice germination was found whose leaf colour turned white (Albino) [7]. Leaf colour of plants resulted from irradiated seed showed change from green to whitish yellow, that these were changes at the genome, chromosome, or DNA level as a result of the disruption of physiological processes in plants [8]. In mutation breeding, abnormalities are not expected, it is expected that the plants will cause diversity in the selected traits so that better traits or characters can be selected, but good characters in the original varieties can be maintained. In line with [4], the higher irradiation dose given to Mira-1 and Bestari rice varieties will inhibit the growth of seed height.

**Figure 1.** The growth of Sidikalang cultivar rice seedlings at 4 WAP irradiated with gamma rays

Determination of LD-50 is one way to know the radiosensitivity of a plant. Radiosensitivity aims to obtain the LD-50 dose, which is the dose that causes 50% of the deaths of the irradiated population. Based on the results of the fit cubic curve analysis, the LD-50 value of the germination percentage of Sidikalang rice cultivar is 586.446 Gy with the equation \( Y = 92.230687 + 0.18876334x + 0.00066281144x^2 + 3.7197261e.007x^3 \). The radiosensitivity curve of Sidikalang rice cultivar was depicted by the cubic curve analysed using Curve Expert 1.3 (Figure 2.)

**Figure 2.** Effect of gamma irradiation on germination percentage of Sidikalang cultivar rice seeds
The LD-50 value is different for each type of plant depending on the part of the plant irradiated, the phase of plant growth and development. In previous studies radiosensitivity in food plants (soybeans) has been reported, the LD-50 value of Argomulyo soybean was 457.13 Gy [9]. In rice, the LD-50 value of local black upland rice cultivars of West Sumatra is 347 Gy [5]. The LD-50 value of the Mira-1 variety is 677.27 Gy and the Bestari variety is 683.68 Gy [4]. This shows that the LD-50 value of the upland rice CV. Sidikalang is higher than the black upland rice West Sumatra. This is due to the effect of the lower sensitivity level of Sidikalang rice seeds to gamma ray irradiation but higher to Mira-1 and Bestari rice seeds.

Several factors affect the level of plant radiosensitivity, such as plant morphology, namely shoots, seeds, pollen, mature plant seeds when irradiation occurs, related to the water content of plant seeds. In this study, the part of the plant that was irradiated was rice seeds. The water content in the seed cells would react with the kinetic energy of gamma ray irradiation and would produce free electrons that collided in various directions where physiologically free electrons could induce the formation of radicals that could react with macromolecules such as protein and fat so that it will affect the metabolic processes and physiology of cells [10]. Gamma ray irradiation in high doses generally produces an inhibitory effect on germination [11], decreased auxin levels or chromosomal damage [12], while low doses of radiation generally produce a stimulating effect on germination through increased enzyme activity, improvement respiration cells, and increase the production of reproductive structures [13].

4. Conclusions

Induction of gamma ray irradiation in Sidikalang rice cultivars changes plant height. The higher radiation dose given, the lower plant height resulted. The lethal dose (LD-50) of the germination percentage of Sidikalang rice cultivar is 586.446 Gy.

References

[1] Balai Besar Penelitian dan Pengembangan Bioteknologi dan Sumberdaya Genetik Pertanian [The Center for Research and Development of Agricultural Biotechnology and Genetic Resources] 2011 Pemanfaatan sinar radiasi dalam pemuliaan tanaman [Utilization of radiation rays in plant breeding] Warta Penelitian dan Pengembangan Pertanian 33 1 pp 7–8

[2] Parry M A J, Madgwick P J, Bayon C, Tearall K, Hernandez-Lopez A, Baudo M, Raskzegi M, Hamada W, Al-Yassin, Quabbou H, Labhilili M and Phillips A L 2009 Review paper: Mutation discovery for crop improvement J. Exp Bot. 60 10 pp 2817–25

[3] Kovács E and Keresztes A 2002 Effect of gamma and UV-B/C radiation of plant cells Micron. 33 pp 199–210

[4] Destavany V 2019 Keragaan karakter agronomi dan studi LD50 mutan padi varietas MIRA-1 dan Bestari Generasi M1 hasil iradiasi sinar gamma [Performance of agronomic characters and LD50 study of MIRA 1 and Bestari Generation mutant rice varieties resulting from gamma ray irradiation] Bachelor thesis (Jakarta: Fakultas Sains dan Teknologi [Faculty of Science and Technology] Universitas Islam Negeri Syarif Hidayatullah)

[5] Warman B, Sobrizal, Suliansyah I, Swasti E and Syarif A 2015 Perbaikan genetik kultivar padi beras hitam lokal Sumatera Barat melalui mutasi induksi [Genetic improvement of local black rice cultivars of West Sumatra through induced mutations] Jurnal Ilmiah Aplikasi Isotop dan Radiasi 11 2 pp 125–35

[6] Jan S, Parween T, Siddiqi T O and Mahmooduzzafar 2012 Effect of gamma radiation on morphological, biochemical and physiological aspects of plants and plant products Environ. Rev. 20 pp 17–39

[7] Sobrizal 2008 Mutasi Induksi untuk mereduksitinggi tanaman padi galur KI 237 [Induced mutation for reducing plant height of rice line KI 237] Jurnal Ilmiah Aplikasi Isotop dan Radiasi 4 2 pp 99-108

[8] Soeranto H 2003 Peran IPTEK Nuklir dalam pemuliaan tanaman untuk mendukung industri pertanian [The role of nuclear science and technology in plant breeding to support the agricultural
industry] Prosiding Pertemuan dan Presentasi Ilmiah Penelitian Dasar Ilmu Pengetahuan dan Teknologi Nuklir P3TM-Batan [Meeting Proceeding and Scientific Presentation on Basic Research of Nuclear Science and Technology] (Yogyakarta: P3TM-Batan) pp 308–16

[9] Hanafiah D S, Trikoesoemaningtyas, Yahya S and Wirnas D 2010 Studi radiosensitivitas kedelai [Glycine max (l) Merr] varietas Argomulyo melalui iradiasi sinar gamma [Radiosensitivity study of Argomulyo soybean (Glycine max L Merill) through gamma ray irradiation Bionatura Jurnal Ilmu-IImu Hayati dan Fisik 12 2 103–9

[10] Van Harten A M 1998 Mutation Breeding: Theory and Practical Applications (New York: Cambridge University Press) pp 243–353

[11] Kumari R and Singh Y 1996 Effect of gamma rays and EMS on seed germination and plant survival of Pisum sativum L. and Lens culinaris Med. Neo Botanica 4 1 25–9

[12] Sparrow A and Woodwell G 1962 Prediction of the sensitivity of plants to chronic gamma irradiation. Radiation Botany 2 1 pp 9–12

[13] Luckey T 1998 Radiation hormesis: Biopositive effect of radiation Radiation Science and Health (Boca Raton, FLO, USA: CRC Press)

Acknowledgements

The author would like to thank the Education Fund Management Institution (LPDP) for the Indonesian Domestic Lecturers (BUDI-DN) for funding the author in carrying out this research.