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**| RESEARCH ARTICLE**

# Cobalt 60 ($^{60}$Co) Gamma Ray Irradiation for Genetic Improvement of Edamame Plant Growth and Yield *(Glycine max*. (L) Merril) M2 Generation

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**| ABSTRACT**
This study aims to examine the value of genetic diversity and heritability in the agronomic character of the M2 generation of Ryoko variety edamame plants and obtain the M2 generation of genjah-aged edamame plants that can adapt well to lowlands. The study used a single plant, with 288 plants planted, with each dose of 48. One treatment factor used in this study is the dose of 60Co gamma-ray irradiation consisting of 6 levels: 0 Gy, 100 Gy, 200 Gy, 300 Gy, 400 Gy, and 500 Gy. The results showed that 60Co gamma-ray irradiation influenced the germination percentage of edamame plants. The results of 60Co gamma-ray irradiation also affect the diversity of qualitative characters of edamame plants, especially in the leaf shape component. However, it does not influence the flower color and growth type components. The diversity of edamame plants caused by the results of 60Co gamma ray irritation impacts the shape of edamame leaves. The results of 60Co gamma-ray irradiation affect the agronomic character of edamame plants, especially in the growth and production components. Plant growth components include plant height, number of leaves, number of branches, flowering age, and harvest age. The elements of crop production include number of pods, weight of 100 seeds, and number of seeds per pod. The results of 60Co gamma-ray irradiation affect the genetic diversity of Generation M2 edamame plants, with the emergence of diverse phenotypes in each individual. Generation M2 edamame plants of the Ryoko variety grown in lowland areas have different genetic diversity values in each agronomic character observed. The value of the coefficient of genetic diversity in these characters ranges from 4.29% - 10.74%. On the other hand, the results of 60Co gamma-ray irradiation cause a decrease in protein levels in edamame. The highest average amount of protein content was shown at the 100 Gy dose of 18.05 g, and the lowest average at the 500 Gy dose of 16.12 g. The protein content of edamame seeds at 100 Gy had the highest protein content but showed no difference with the dose of 0 Gy (Control). In general, the productivity of edamame plants is determined by genetic characteristics and environmental factors. Potential yields on edamame plants can be achieved if the plant does not experience interference with biotic and abiotic factors during the growing period.

**| KEYWORDS**

Edamame, heritability, Irradiation, kkg, growth, yield

**| ARTICLE INFORMATION**

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## 1. Introduction

Edamame is an export-oriented commodity because, in real terms, it has a higher economic value than ordinary soybeans. One of the strategies to increase edamame production is by planting superior cultivars. Planting superior cultivars must be balanced with the availability of superior seeds and good seed quality (Ramadhani. et al., 2016). There needs to be more than edamame in Indonesia; therefore, it is necessary to increase production. Edamame also has extensive export market opportunities. Export demand from Japan is 100,000 tons per year, and America is 7,000 tons per year. Meanwhile, Indonesia can only meet 3% of Japan's market needs, while China and Taiwan meet 97% of others.

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Edamame productivity is very high, the life of edamame is relatively long, the pod size is more significant, and the taste is sweet. This type of soybean is also much sought after by consumers for snacks. In addition, edamame is only suitable for development in the highlands, which are carried out in Bogor and Lampung, because it has good potential for edamame seed centers. Meanwhile, in lowland areas, it still needs to be adequately cultivated. One of the efforts that can be made to meet the needs of edamame in Indonesia is to provide high-yielding varieties through a plant breeding program. Therefore, it is necessary to carry out genetic improvement of edamame seeds. Improving plant genetic traits can be done through plant breeding programs, and the first step is to enlarge genetic diversity to enhance genetic progress. Efforts to enlarge genetic diversity can be made in various ways, including crossing and mutation induction.

Several mutagenic agents, such as physical mutagens and chemical mutagens, can produce mutations. Physical mutation agents include X-rays, gamma rays, neutrons, alpha, beta, proton, deuteron particles, and ultraviolet radiation. Chemical mutation agents include alkyl agents (EMS), exposides, alkaloids, peroxides, and formaldehyde (Suryo, 2003). Gamma-ray radiation can be emitted by 60Co, 137Cs. The mutation is a sudden and random change in genetic material (genome, chromosome, and cell) that aims to improve plant genetics (Sumpena et al., 2013). To determine the amount of radiation of a radioactive ray to a variety, dose orientation is first carried out because each material or organism has a different sensitivity (radiosensitivity) (BATAN, 2012). The results of the study Fatma et al. (2023) gamma-ray dose orientation to growth and edamame results are determined from *Lethal Dose* (LD) values of 20% and 50%, which means that sensitivity to radiation can be measured based on *Lethal Dose* (LD) values, which are doses that cause death from irradiated plant populations. LD values of 20% and 50% in the dose range of 143.32 and 551.881 in the first generation (M1) of 60Co gamma-ray irradiation on edamame at doses of 100 Gy, 200 Gy, 300 Gy, 400 Gy and 500 Gy affect the character of plant height, number of leaves, leaf shape, number of productive branches, number of pods, harvest age, number of seeds, and number of seed weights per plant.

Meanwhile, doses above 500 Gy can cause abnormal germination or damage. This can occur because plant genetic factors cause it. This research is one of the efforts to improve the quality of edamame soybean seeds by mutation plant breeding methods. The edamame variety used in this study was the Ryoko variety irradiated by 60Co Gamma rays at 100 to 500 Gy doses. The expected results in the M2 generation can increase genetic diversity, obtain edamame plants with superior characteristics, and are mature and able to adapt to different environments, especially at high altitudes in lowlands.

The purpose of this study is to examine the value of genetic diversity and heritability in determining the agronomic character of the M2 generation of Ryoko variety edamame plants, as well as to obtain the M2 generation of genjah-aged edamame plants and their ability to adapt well to lowlands.

## 2. Literature Review

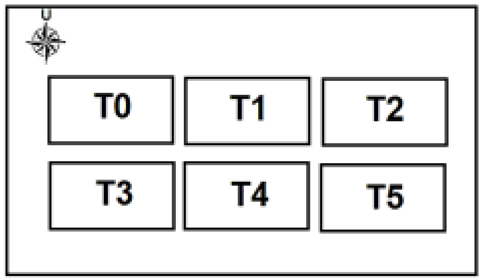
Research conducted by Handayani et al. (2020) shows that the treatment by giving a low dose of irradiation to edamame can produce a diversity of desired characteristics. The advantage of using low doses of gamma-ray irradiation is that it allows mutations in minor genes observed in later generations without adverse mutations occurring. The diversity of agronomic characters of edamame plants after gamma-ray irradiation is genetically controlled. High diversity affects the determination of the selection process because the genetic response to selection depends on the level of genetic diversity. Research conducted by Lilik and Yulidar (2015) shows that the treatment of physical mutagens in the form of gamma rays with one of the sources using 60Co gamma rays has an extreme penetrating power so that it can be used to increase genetic diversity in the assembly of varieties. This aligns with research conducted by Kurniajati et al. (2021) that success in inducing genetic diversity is determined by plant radio sensitivity measured through LD50 values. This value can kill 50% of the plant population and is considered the optimum dose because it can produce mutants or the highest genetic diversity. Low doses of gamma-ray irradiation can also stimulate cell division, growth, and development of various organisms.

On the other hand, research conducted by Norman (2013) shows that edamame seeds produced in the highlands can provide better plant growth than seeds produced in the lowlands. The difference is seen in plant height, plant weight, and seed germination percentage parameters. Edamame seeds produced in the highlands are greener, the size of the seeds, and the percentage of fat content is smaller than the seeds produced in the lowlands. In Virginia, Jiang et al. (2018) evaluated 86 edamame breeding strains in terms of yield and agronomic properties and found high breadth heritability for the fresh weight of 100 seeds (87.96%) and plant height (79.22%). Similarly, high to moderate and stable heritability values were observed for protein (79.39%), oil (74.62%), stachyose (68.73%), and fiber (56.95%) content in edamame varieties.

## 3. Methodology

Regency with an altitude of ± 340 meters above sea level with an average temperature range of 23°C -33°C. The materials used in this study include edamame seeds of the M-2 generation of the Ryoko variety originating from Jember harvested in the M1 generation, which had previously been irradiated by $^{60}$CO gamma rays at the Central Laboratory of Isotope Application and

Irradiation of the National Nuclear Energy Agency (BATAN), with 5 dose levels, namely, 100 Gy, 200 Gy, 300 Gy, 400 Gy, and 500 Gy, with Gammacell 220, seedling/tray media, 40x40 polybags, and planting media. The planting medium used is soil and manure in a ratio (3: 1). The chemical fertilizer used is NPK Mutiara (16:16:16). Fungicides and insecticides are used according to the symptoms of pest attacks caused. Tools used in this study include ajir, label board (wood lat), stationery, analytical scales, scissors, drill, timba, tape/ruler, hoe, calculating tool, documentation camera, and computer for data analysis. This study was conducted using a single plant, with 288 plants planted, with each dose of 48 plants. There is one treatment factor used in this study, namely, the dose of $^{60}$Co gamma ray irradiation consisting of 6 levels with the following code: T0: no irradiation (control), T1: irradiation dose 100 Gray, T2: irradiation dose 200 Gray, T3: irradiation dose 300 Gray, T4: irradiation dose 400 Gray, and T5: irradiation dose 500 Gray




Description: T0, 2, 3, 5 = $^{60}$Co gamma ray irradiation dose

**Figure 1.** Research Plan of Edamame Planting in the Field

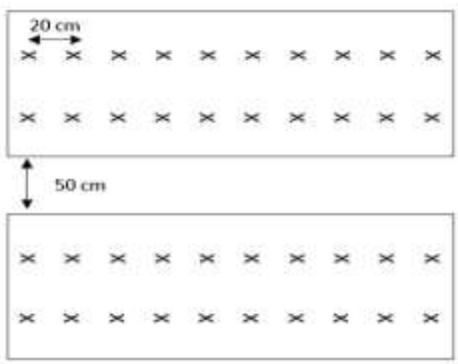



**Figure 2.** Edamame Plant Population in One Experimental Plot

The experiment was carried out without any repetition because each material irradiated had a different genetic potential. Each experimental plot consisted of 35 plants, and observations were made on all plant populations (Figure 1).

***3.1. Research Implementation***

***3.1.1 Seed preparation***

The seeds used are edamame seeds of the M-2 generation Ryoko variety irradiated by $^{60}$Co gamma rays with doses of 0 Gray, 100 Gray, 200 Gray, 300 Gray, 400 Gray, and 500 Gray. The seeds to be treated are selected first to select good quality seeds. Seed selection is carried out by grouping seed sizes from large, undamaged, not hollow, and not wrinkled seed sizes. Edamame seeds that have been uniformed are then seeded on the prepared seedbed media.

***3.1.2 Seedbeds and Nurseries***

Irradiated edamame seed seedbeds are carried out on seedbed media using soil and manure media (3 1). Seeds were planted as many as 48 seeds from each irradiation dose treatment. After the seeds germinate, the percentage of germination is carried out. Observation of seed germination is carried out at 14 HSS (day after sowing). Observation of germination variables can be done by calculating the percentage of seed germination (percentage of normal and abnormal sprouts). Seeding can be done by transferring all edamame seeds that have grown to the prepared polybag planting media and recording all plants that have morphological characteristics that appear different from seeds that are not irradiated or controlled. Then, prepare the planting medium; after that, the seedlings are transferred to a polybag planting media measuring 40 x 40 cm at the age of 14 days after sowing.

### 3.1.3 Preparation of Growing Media

Preparation of planting media is carried out two weeks before planting; planting media is made by mixing soil and cage in a ratio of 3 1. Before use, the soil medium has been incubated for two weeks. Incubation is intended so that the reaction of organic matter and soil can run well and that the availability of nutrients in the soil can spur the process of plant growth properly. All planting media materials are mixed and flattened using a hoe, then put into a 40 x 40cm polybag. Edamame seedlings planted 2 plants per polybag. Transplanted seedlings are then watered moderately. The maintenance of edamame plants includes watering (watering), weeding, fertilizing, and spraying when there is a pest or disease attack. Fertilization on edamame plants can be done when the plants are 7 hst, 14 hst, 28 hst. According to Fahmi et al. (2015), the recommended dose of fertilizing edamame plants includes NPK, KCl, SP36, and Urea. The doses of edamame fertilization are in Table 1

**Table 1.** Dosage of Edamame Plant Follow-up Fertilization

| Growth Phase | Type of fertilizer | Application |
|---|---|---|
| Copper Vegetative 7hst | - NPK (16:16:16), 4.8 g/plant<br>- Manure application | Leaked |
| Vase Vegetative<br>(Following I) 14 hst | - NPK (16:16:16), 4.8 g/plant<br>- SP36 1.2 g/plant | Leaked |
| (Following II) 28 hst | - NPK (16:16:16), 4.8 g/plant<br>- KCl 0.4 g/plant | Leaked |

### 3.2 Harvest

Edamame can be harvested in the age range of 60-75 for fresh produce, but if produced for seed needs, it can be harvested in the range of 90-115 HST. The process of harvesting edamame can be done by pulling the plant from the base of the stem. Physiologically, ready-to-harvest edamame is characterized by brownish-green fruit pods; there are 2-4 fruit seeds per pod of yellowed soybean leaves. The collection of edamame seeds is carried out based on the treatment dose (labeling) given. Edamame seeds are carried out air drying or up to weight shrinkage of 24-25%.

### 3.3 Observation Variables

The observational variables used in this study include germination percentage (%), qualitative character, agronomic character, genetic diversity value, and heritability.

1. The percentage of germination is carried out at the age of 14 days after seedling (hss). Germination is a measure that seeds contain structure and substance, including enzyme systems that provide the ability to germinate under suitable or optimal environmental conditions. The calculation of irradiated edamame germination was carried out when plants were 14 days old after seedling (hss) (ISTA, 2018). The formula for calculating the percentage of seed germination of each dose is calculated by the formula:
   Germination percentage = $\frac{a\ lot\ of\ germinated\ seeds}{many\ sheeds\ planted}$ x 100%
2. Qualitative characters of edamame observed in the vegetative phase (pre-harvest) include; flower color, growth type, and leaf shape. The qualitative character of edamame is observed in the vegetative (pre-harvest) phase.
3. Agronomic characters observed in the generative phase (post-harvest) include observation of plant height, number of tillers, number of productive branches, number of leaves, flowering age, observation of number of pods, total number of pods per plant, seed weight of 100 grains. Plant height was observed at the age of 14 hst, 28 hst, 42 hst, 56 hst, 70 hst, 84 hst, until the plant height did not increase again. The number of saplings is calculated when the plant has flowered, assuming that at that time, no new saplings are formed. The flowering age is observed when the first panicles appear from each plant.

### 3.4 Analysis up Protein

Analysis of protein content in edamame results of $^{60}$Co gamma ray irradiation is to determine the protein levels contained in edamame soybeans. The analysis data used are presented in Table 3.2

**Table 2.** Methods of analyzing the protein content of edamame

| Variable | Parameter | Measuring Instruments | Data Scale |
|---|---|---|---|
| Total protein levels in edamame resulting from $^{60}$Co gamma ray irradiation | Titrimeters | Method Kjedahl | Ratio |

### 3.5 Data Analysis

#### 3.5.1 T Test

A t-test was performed to compare each treatment dose of $^{60}$Co gamma ray irradiation (100 Gy – 500 Gy) with control (0 Gy). The t-test analysis is performed by comparing the calculated t values and the table t. According to (Kusumaningrum, 2008), how to find t count is as follows:

t count = $\frac{|\underline{A}-\underline{B}|}{S_{(\underline{A}-\underline{B})}}$

$S_{(\underline{A}-\underline{B})}$ = where and $\sqrt{\frac{S^2A+S^2B}{n}}$ $S_A^2 = \frac{1}{n}\sum_{i=1}^{n} \left(A_i - \underline{A}\right)^2$ $S_B^2 = \frac{1}{n}\sum_{i=1}^{n} \left(B_i - \underline{B}\right)^2$

Information:

| | |
|---|---|
| $\underline{A}$ | : Average value of sample A |
| $\underline{B}$ | : Average value of sample B |
| $S_{(\underline{A}-\underline{B})}$ | : Standard Error |
| $S_A^2$ | : Variant value (variety) A |
| $S_B^2$ | : Variant value (variety) B |
| $A_i$ | : sample value A to i |
| $B_i$ | : sample value B to i |
| n | : sample size |

#### 3.5.2 Standard Deviation

Standard deviation is a parameter used to measure the distribution of data values. According to Saputra (2015), the standard deviation formula is as follows:

$$\boldsymbol{S} = \frac{\sqrt{\mathbf{n}\sum\mathbf{Xi}^2 - (\sum\mathbf{Xi})^2}}{\mathbf{n}\,(\mathbf{n-1})}$$

Information

s: standard deviation value
n: number of samples
Xi: sample value X to i

#### 3.5.3 Phenotype Diversity Value

Phenotype diversity is a genetic estimation parameter used to determine the extent of diversity of a plant character based on phenotype (Handayani and Hidayat, 2012). The phenotypic variety ($\sigma^2$p) of the M2 generation of edamame plants of the Ryoko variety is calculated by the diversity formula (variance):

$$\sigma^2 M2 = \frac{\sum_{i=1}^{n}(\mathrm{Xi} - \mu)^2}{N}$$

Information:

| | | |
|---|---|---|
| $\sigma^2$ M2 | : | Variety of M2 phenotypes |
| Xi | : | The value of the character of each individual observed in the plant population of |
| μ | : | generation M2 |
| N | : | The median value of each character in the plant population of generation M2 |
| | | The number of plant populations of generation M2. |

The coefficient of genetic diversity (KKG), according to Singh and Caudhari (1977 in Hanafiah, Yahya, and Wirnas, 2010), is calculated using the following formula:

$$KKG = \frac{\sqrt{\sigma^2 \mathrm{g}}}{\mathrm{X}}\, x\ 100\%$$

Information:

$\sigma^2$ g: Genetic Diversity
X: Average Population

The criteria for the breadth and narrowness of the genetic diversity coefficient, according to Halide (2020), are based on the value of the genetic diversity coefficient, namely low (<25%), medium (25% - 50%), and high (>50%).

### *3.6 Heritability*

Heritability is one of the estimations of genetic parameters that shows the proportion of genetic influence on appearance or phenotype in generation-2 (M2) plants of Ryoko variety edamame soybeans. According to Jacob *et al.* (2012), heritability can be formulated as follows:

$$h^2 = \frac{\sigma^2 g}{\sigma^2 f} \times 100\%$$

Information:

H2 : Heritability
$\sigma^2$g : genetic variation
$\sigma^2$f : phenotypes Variation

Furthermore, heritability values, according to Suryati (2014), are grouped based on criteria: low (h2 <20%), medium (20% < h2 < 50%), and high (h2>50%).

## 4. Results and Discussion

### *4.1 Germination Percentage (%)*

The percentage of seed germination is obtained from the number of seeds that germinate from the total seeds sown during the study. Germinated seeds are categorized into 2. That is abnormal sprouts and normal sprouts. Abnormal sprouts are seeds that do not sprout, and normal sprouts are seeds that grow. The percentage of germination of irradiated Ryoko generation M2 edamame seeds is presented in table 3

**Table 3.** Germination Percentage of Ryoko Variety M2 Generation Edamame Seeds Based on the Results of $^{60}$Co Gamma Ray Irradiation Given

| Dosage Treatment (Gy) | The Amount of Seeds that Germinated | Germination Percentage (%) |
|---|---|---|
| 0 | 48 | 93.75 |
| 100 | 48 | 95.83 |
| 200 | 48 | 85.42 |
| 300 | 48 | 81.25 |
| 400 | 48 | 75.00 |
| 500 | 48 | 68.75 |

Table 3 shows that edamame soybeans of the Ryoko variety resulting from $^{60}$Co gamma ray irradiation dose 0 Gy-500 Gy have a good or normal germination percentage. It is known from the table that the higher the dose of radiation administered, the smaller the germination. Some edamame plants experience abnormal germination. 60Co gamma ray radiation can cause changes in plant growth by stimulating seed growth or damaging seed growth.

In Sirajudin's opinion (2010) states that giving too high a dose of $^{60}$Co gamma ray irradiation can cause permanent damage to DNA and proteins, inhibit enzyme activity, and disrupt plant physiological processes. Table 1 shows that edamame plants irradiated by $^{60}$Co gamma rays at a dose of 500 Gy have the lowest germination percentage, which is 68.75%. While the highest germination percentage with a dose of 100 Gy, which is 95.83%. The difference in germination percentage is related to the general effects of radiation that are often shown damage to plant physiology. At each dose, there are abnormal seeds so that the seeds are not able to germinate and do not grow into plants; this is in line with the research of Sanipar J et al. (2013), whose results show that the initial effect of mutations is shown by seed germination, indicated by the presence of abnormal sprouts.

### *4.2 Qualitative Character Diversity of Generation M2 Edamame Ryoko Variety*

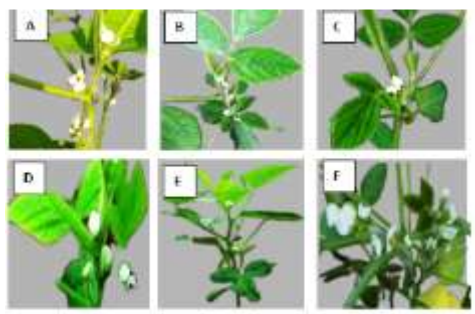
Generation M2 edamame plant variety Ryoko is a plant resulting from gamma ray irradiation of $^{60}$Co in generation M1 using doses of 100 Gy., 200 Gy., 300 Gy., 400 Gy. And 500 Gy. $^{60}$Co gamma ray irradiation is known to increase genetic diversity in the character of a plant, one of which is diversity in qualitative characters. Each individual of the M2 generation edamame shows diverse traits in each character, which can be identified through the percentage of qualitative character diversity. Determining the percentage of qualitative diversity of edamame generation M2 is important to know in order to determine morphological differences in an observed edamame plant variety. Edamame generation M2 planted in this study as many as 288 plants; where each dose of treatment, there were 48 plants. The percentage of diversity is the number of plants with similar characteristics divided by the total generation of M2 edamame plants according to the predetermined dose level of $^{60}$Co gamma ray irradiation

**Table 4.** Qualitative Character Diversity of Edamame Plant Generation M2

| Character | Gamma ray irradiation dose $^{60}$Co | | | | | | Percettase |
|---|---|---|---|---|---|---|---|
| | **0 Gy** | **100 Gy** | **200 Gy** | **300 Gy** | **400 Gy** | **500 Gy** | |
| Flower Color | white | white | white | White | white | white | 100 |
| Leaf shape | Normal | Normal | Normal | Normal | Normal | Normal | 60 |
| | Dwarf | Dwarf | Dwarf | Dwarf | Dwarf | Dwarf | 20 |
| | Abnormal | Abnormal | Abnormal | Abnormal | Abnormal | Abnormal | 20 |
| Grow Type | Determinate | Determinate | Determinate | Determinate | Determinate | Determinate | 100 |

#### *4.2.1 Flower Color*

The Ryoko variety M2 generation edamame plant does not show any diversity in flower color. This is indicated by the absence of different color variations in each individual in the population. Edamame plants without irradiation treatment (control) have white flowers. This was also shown by all individuals of the M2 generation edamame plant resulting from $60^{Co}$ gamma ray irradiation at a dose of 100Gy-500 Gy (Figure 3). $60^{Co}$ gamma ray irradiation carried out at each dose does not cause changes in flower color.



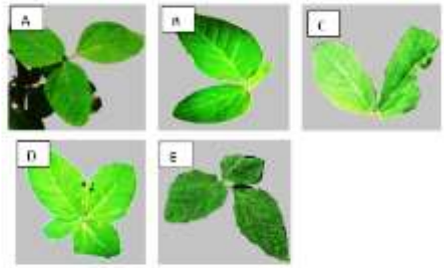

Description: The color of irradiated flowers tends not to vary;
a) dose 0 Gy, b) dose 100 Gy, c) dose 200 Gy, d) dose 300 Gy,
e) a dose of 400 Gy, and f) a dose of 500 Gy

**Figure 3.** The color of the flowers of the edamame variety Ryoko plant is the result of gamma ray irradiation $^{60}$Co

The M2 generation edamame plant of the Ryoko variety resulting from $^{60}$Co gamma ray irradiation does not show any diversity in flower color. This is indicated by the absence of different color variations in each individual in the population. Edamame plants without irradiation treatment (control) have white flowers. This was also demonstrated by the whole individual edamame plant dose of 100Gy-500 Gy (Figure 3). According to Da Silva et al. (2017), edamame plants generally have white or purple flower colors. However, on the other hand the purple color also has variations according to the genotype of the cultivar. The w1w1 and w1W1 alleles are color-coding alleles in edamame flowers. W1W1 is the dominant allele that produces purple color in edamame plant flowers, while the w1w1 allele is a recessive allele that plays a role in producing white color in edamame flowers. The occurrence of the mutation process depends largely on whether or not the allele that controls the color of the flower is exposed.

#### *4.2.2 Leaf shape*

The M2 generation edamame plant of the Ryoko variety shows a diversity of leaf shapes. This is indicated by the shape of leaf variation in each individual in the population. The treatment of $^{60}$Co gamma ray irradiation dosage is able to affect the structure and function of plant cells, especially in leaf shape. Gamma radiation sourced from coblat $^{60}$Co causes morphological changes in leaves. Including changes in leaf size. And the shape or color of the leaves. $^{60}$Co gamma ray irradiation shows varying effects on edamame plants depending on the level of exposure and exposure time. Changes in leaf shape that occur in edamame plants are shown in Figure .4



Description: a. Normal leaves, b. 3-stranded leaves of one size dwarf, c. abnormal leaves, d. 4 strands of leaves, and e. Leaf strands 3, and there are white spots on the surface of the leaves

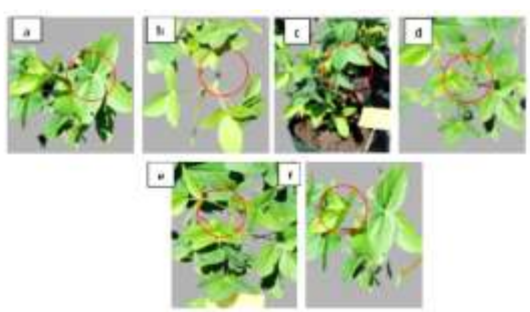
**Figure 4.** The shape of the leaves of the edamame vaietas Ryoko plant is irradiated by $^{60}$Co gamma rays

$^{60}$Co gamma ray irradiation can affect the shape of edamame leaves. This is shown in Figure 4.b. the shape of a triple leaf where one of the leaves is stunted. The leaves were found on plants with radiation treatment of 200 Gy and 300 Gy. In figure 4.c., there are abnormal leaves in the form of two simple primary leaves that are not round or oval in shape. The leaves were found on plants with radiation treatment of 400 Gy and 500 Gy. Figure 4.d. shows 1 leaf canopy totaling 4 leaves found on plants with a radiation dose of 100 Gy. Leaves that have whitish spots, as shown in Figure 4.e., were found on plants with a radiation dose of 100 Gy.

The diversity of edamame plants caused by the results of $^{60}$Co gamma ray irritation has an impact on the shape of edamame leaves. Edamame leaves are divided into four types, namely: (1) cotyledons or seed leaves, (2) two simple primary leaves, (3) three leaves, and (4) profila (Adie and Krisnawati, 2007). The shape of edamame leaves irradiated by $^{60}$Co gamma rays has undergone several changes. There are changes in the shape of edamame leaves found at each dose, including one leaf blade being stunted, an abnormal or incomplete leaf blade shape, and white spots on the leaf surface (Figure 4). The shape of the leaf shown is a leaf with two simple primary leaves; one of the leaves has an irregular or incomplete shape. The results of $^{60}$Co gamma ray irradiation at a dose of 100 Gy showed the number of leaves in one clump totaling 4 strands. The results of $^{60}$Co gamma ray irradiation at doses of 200 Gy and 300 Gy changes that occur show the shape of three leaves where one of the leaf sizes is dwarfed. The results of $^{60}$Co gamma ray irradiation at doses of 400 Gy and 500 Gy, there is an abnormal change in leaf shape, where there are two simple primary leaves that are not round or oval in shape. In Figure 4, it was also seen that the results of $^{60}$Co gamma ray irradiation at a dose of 100 Gy edamame leaves showed whitish spots on the leaf surface. The changes that occur in the physical leaves of the edamame plant show that Mutai can cause changes in plant DNA, which is then expressed in the physical form of the plant. However, the changes that have occurred have not been stable. The traits that arise due to the radiation process will begin to stabilize and will be inherited in the next generation, namely in the M3 generation and so on

### *4.2.3. Growth Type*

The Ryoko variety of the M2 generation edamame plant does not show any diversity in plant growth types. This is shown by all individual M2 generation edamame plants; both plants with control treatment (irradiation marks) and plants resulting from $^{60}$Co gamma ray irradiation dose of 100 Gy-500 Gy have determinate growth types (Fig.5). $^{60}$Co gamma ray irradiation carried out at each dose does not cause changes in growth type in edamame plants. This type of determinate growth is characterized by the characteristic vegetative growth of terminal shoots stopped when flowering occurs (Fig.5).



Information: The growth type resulting from $^{60}$Co gamma ray irradiation at each dose tends not to Show diversity: a) dose 0 Gy, b) dose 100 Gy, c) dose 200 Gy, d) dose 300 Gy, e) dose 400 Gy, f) dose 500 Gy.

**Figure 5**. Growth type of edamame vaietas Ryoko plant resulting from gamma ray irradiation $^{60}$Co

The results of $^{60}Co$ gamma ray irradiation do not show any diversity in the type of edamame plant growth. This is indicated by the absence of variation in the type of growth in each individual in the population. Edamame plants without irradiation treatment (control) have a determinate growth type. This is also shown by the whole individual plant edamame dose of 100Gy-500 Gy. Plants with determinate growth types are characterized by vegetative growth characteristics of terminal shoots stopped when flowering occurs. In general, edamame plants have 3 types of growth, namely determinate, indeterminate, and semi-determinate (Da Silva et al., 2017). According to Rukmana & Yuniarsih (2012), the determinite growth type in edamame plants has the main advantages in the simultaneous flowering process, and plant height is included in the short category so that soybean plants do not fall down easily and are susceptible to disease attacks.

### *4.3 Agronomic character*

#### *4.3.1. Plant Height(cm)*

The results of the T Test analysis showed that the results of $^{60}Co$ gamma ray irradiation as a whole showed a difference in the height of edamame plants aged 14-84 HST. The results of $^{60}Co$ gamma ray irradiation showed a very noticeable difference in the treatment of 300 Gy, 400 Gy, and 500 Gy. The T test was performed by comparing the levels of 1% and 5% of the $^{60}Co$ gamma ray irradiation dose treatment with the control treatment, respectively. Edamame plant height was observed in plants aged 14 HST to 84 HST or until the plant showed no growth. The average value of the height of the Ryoko variety edamame plant resulting from $^{60}Co$ gamma ray irradiation is in table 4.

**Table 4.** Average Height of Edamame Plant Ryoko Variety Irradiated by $^{60}Co$ Gamma Rays

| Dosage Treatment (Gy) | Plant Height (cm) HST | | | | | |
|---|---|---|---|---|---|---|
| | 14 | 28 | 42 | 56 | 70 | 84 |
| 0 | 21,83 | 30,27 | 35,46 | 36,19 | 38,31 | 38,88 |
| 100 | 22,00 | 30,08 | 36,54 | 36,58 | 39,33 | 39,92 |
| 200 | 18,42 * | 25,69* | 31,48 | 33,69 | 34,33 | 34,38 |
| 300 | 16,38** | 22,75** | 28,48** | 28,85** | 31,15* | 31,46** |
| 400 | 14,90** | 21,23** | 24,81** | 26,44** | 28,38** | 28,75** |
| 500 | 14,38** | 19,48** | 23,60** | 23,98** | 24,56** | 24,60** |

Table 4 shows that the height of edamame plants irradiated by $^{60}Co$ gamma rays has a marked difference in plants aged 14 and 28 HST treated with a dose of 200 Gy. While the difference is very noticeable in plants aged 14-84 HST at doses of 300 Gy, 400 Gy, and 500 Gy. The highest average plant height is indicated at a dose of 100 Gy, and the lowest average is indicated at a dose of 500 Gy. The growth of edamame plants at a dose of 100 Gy had good results compared to control plants, but at doses of 200-500 Gy, growth was slower than that of the control treatment.

#### *4.3.2. Number of Leaves (strands)*

The results of the T Test analysis showed that the results of $^{60}Co$ gamma ray irradiation as a whole showed differences in the number of leaves of edamame plants aged 14-84 HST. The results of $^{60}Co$ gamma ray irradiation showed a very noticeable difference in the treatment of 300 Gy, 400 Gy, and 500 Gy. The T test was performed by comparing the levels of 1% and 5% of the 60Co gamma ray irradiation dose treatment with the control treatment, respectively. Observation of the number of leaves was carried out on plants aged 14 HST to 84 HST or until the plant showed no growth. The average value of the number of leaves of the Ryoko variety edamame plant resulting from $^{60}Co$ gamma ray irradiation is in table 5.

**Table 5.** The Average Number Leaves of Ryoko Variety Edamame Plant Irradiated by Gamma Rays $^{60}Co$

| Treatment Dosage (Gy) | Number of Leaves (Strands) HST | | | | | |
|---|---|---|---|---|---|---|
| | *14* | *28* | *42* | *56* | *70* | *84* |
| 0 | 2,44 | 3,46 | 5,90 | 13,90 | 15,73 | 16,19 |
| 100 | 2,46 | 3,56 | 6,15 | 13,96 | 15,88 | 16,48 |
| 200 | 2,15 | 3,25 | 5,15 | 13,31 | 14,38 | 14,75 |
| 300 | 1,85** | 2,81* | 4,23** | 10,65** | 12,08** | 12,31** |
| 400 | 1,67** | 2,52** | 3,92** | 9,58** | 10,48** | 10,79** |
| 500 | 1,44** | 2,19** | 3,52** | 9,58** | 9,98** | 10,19** |

The data in Table 5 showed that the number of leaves on edamame plants irradiated by $^{60}Co$ gamma rays had a marked difference at the age of 28 HST treated at a dose of 300 Gy. While the difference is very noticeable in plants aged 14-84 HST at doses of 300

Gy, 400 Gy, and 500 Gy. The highest average number of leaves is indicated at a dose of 100 Gy, and the lowest average is indicated at a dose of 500 Gy. The number of leaves of edamame plants at a dose of 100 Gy had good results compared to control plants, but at doses of 200-500 Gy, the number of leaves had lower yields compared to the control treatment.

#### *4.3.3. Number of Branches*

The results of the T Test analysis showed that the results of $^{60}$Co gamma ray irradiation as a whole showed differences in the number of edamame plant branches aged 28-56 HST. The results of $^{60}$Co gamma ray irradiation showed a very noticeable difference in the treatment of 300 Gy, 400 Gy, and 500 Gy. The T test was performed by comparing the levels of 1% and 5% of the $^{60}$Co gamma ray irradiation dose treatment with the control treatment, respectively. The number of branches of edamame plants was observed in plants aged 28 HST to 56 HST or until the plants showed no branch growth. The average value of the number of branches of edamame plants of the Ryoko variety resulting from $^{60}$Co gamma ray irradiation is in table 6

**Table 5.** The Average Number of Branches of Ryoko Variety Edamame Plant Results of Gamma Ray Irradiation $^{60}$Co

| Dosage Treatment (Gy) | Number of Branches (fruit) HST | | |
|---|---|---|---|
| | ***14*** | ***28*** | ***42*** |
| 0 | 1,60 | 3,33 | 3,81 |
| 100 | 1,63 | 3,38 | 3,83 |
| 200 | 1,65 | 2,81 | 3,50 |
| 300 | 1,40 | 2,65* | 3,27 |
| 400 | 1,33 | 2,21** | 2,67** |
| 500 | 1,15** | 1,77** | 2,44** |

The data in Table 5 showed that the number of branches in edamame plants irradiated by $^{60}$Co gamma rays had a marked difference at the age of 42 HST treated with a dose of 300 Gy. While the difference is very noticeable in plants aged 28-56 HST at doses of 400 Gy and 500 Gy. The highest average number of branches is shown in the results of a $^{60}$Co gamma ray irradiation dose of 100 Gy, and the lowest average is shown in the results of a 60Co gamma ray irradiation dose of 500 Gy. The number of branches in the 100 Gy dose of edamame plants had good results compared to the control plants, but at the 200-500 Gy dose, the number of branches was lower compared to the control treatment.

#### *4.3.4. Flowering Age and Harvest Age*

The results of $60^{Co}$ gamma ray irradiation affect the flowering age and harvest age of edamame plants. The average value of flowering age and harvest age obtained at the time of observation was tested using the T Test by comparing the levels of 1% and 5% with the control treatment. The average flowering age results in edamame plants showed a marked difference in the treatment doses of 100 Gy and 200 Gy, where the flowering age was earlier than the control. While the age parameter of the edamame plant showed a very noticeable difference at a dose of 500 Gy. The average values of flowering age and harvest age of edamame plants of the Ryoko variety are presented in table 6

**Table 6.** Average Flowering Age and Harvest Age of Edamame Ryoko Variety Irradiated by Gamma Rays $^{60}$Co

| Dosage Treatment (Gy) | Flowering age (HST) | Harvest age (HST) |
|---|---|---|
| 0 Gy | 34,92 | 108,98 |
| 100 | 34,04* | 108,77 |
| 200 | 34,25* | 108,83 |
| 300 | 34,29 | 109,02 |
| 400 | 35,08 | 110,15 |
| 500 | 35,42 | 111,06** |

The data in Table 6 showed that the average value of flowering age showed no noticeable difference in the dosage treatment of 300 Gy, 400 Gy, and 500 Gy. However, the real difference was found in the treatment dose of 100 Gy of 34.04 and 200 Gy of 34.25. The 500 Gy dose treatment had the highest average harvest life compared to the control treatment and showed a very noticeable difference. The mean value of the 500 Gy dose treatment was the highest average value compared to the control treatment, while the 100 Gy and 200 Gy dose treatments showed the lowest average compared to the control.

#### *4.3.5. Number of Pods and Seed Weight (g)*

The results of $^{60}$Co gamma ray irradiation affect the number of pods and the amount of pod content of edamame plants. The average weight value of 100 seeds and the number of pods obtained at the time of observation were tested using the T Test by comparing the levels of 1% and 5% with the control treatment. The average yield of the number of pods in edamame plants showed a noticeable difference at 400 Gy and 500 Gy dose treatments. While the weight parameter of 100 seeds of edamame plants did not show any real difference in each treatment of $^{60}$Co gamma ray irradiation results. The average value of the number of pods and the weight of 100 seeds of the edamame plant of the Ryoko variety are presented in table 7

**Table 7.** Average Number of Pods and Seed Weight (g) Edamame Ryoko Variety Results of Gamma Ray Irradiation $^{60}$Co

| Dosage Treatment (Gy) | Number of pods (fruit) | Weight 100 seeds (g) |
|---|---|---|
| 0 | 11,46 | 43,13 |
| 100 | 11,75 | 43,50 |
| 200 | 10,92 | 43,00 |
| 300 | 9,29 | 42,75 |
| 400 | 8,08* | 42,13 |
| 500 | 8,06* | 42,13 |

The data in Table 7 showed that the mean pod count values showed no noticeable difference in the treatment doses of 100 Gy, 200 Gy, and 300 Gy. However, there was a noticeable difference in the treatment dose of 400 Gy of 8.08 and 500 Gy of 8.06. The 500 Gy dosing treatment had the lowest average number of pods compared to the control treatment. The average weight value of 100 seeds of edamame plants in each treatment showed no noticeable difference. The mean value of the 100 Gy dose treatment was the highest average value compared to the control treatment of 43.50 g, while the 400 Gy and 500 Gy dose treatments showed the lowest average of 42.13 g.

Based on the data in Table 7, the radiation dose of 100 Gy shows the highest average value of the number of pods at 11.75. Plants irradiated at a dose of 500 Gy had the lowest average value of 8.06. The number of pods produced by edamame plants has a pattern of relationship to the number of flowers produced. If the two have a positive relationship, then it will be beneficial. However, if the relationship between the two is negative, it will have a negative impact on crop production. The number of flowers produced is not proportional to the number of pods produced. This can be caused by the possibility of flower loss when plant growth takes place. Decreasing the number of flowers produced by plants can affect the number of pods that can be harvested. This is evidenced in research conducted by Anggraito and Pukan (2015), where the results of the study showed a decrease in flowers produced by koro bean plants related to the number of filled pods that can be harvested. The abundance of fallen flowers will lead to low pod formation efficiency.

#### *4.3.6. Number of Seeds per Pod*

The results of $^{60}$Co gamma ray irradiation affect the number of seeds per pod of edamame plants. The exact effect of gamma radiation on the number of seeds per pod can vary depending on a number of factors, including the level of radiation exposure, the duration of exposure, and the type of plant involved. The average value of the number of seeds per pod was obtained at the time of observation, testing using the T Test by comparing the levels of 1% and 5% with the control treatment. The average yield of the number of seeds per pod of edamame plants showed a noticeable difference at the treatment dose of 300 Gy on pods of content 2, while at doses of 400 and 500 Gy, it showed a very real effect on pods of seed contents 2. The average value of the number of seeds per pod of edamame plants of the Ryoko variety is presented in table 8

**Table 8.** Average Number of Seeds per Edamame Pod of Ryoko Variety Gamma Ray Irradiation Results $^{60}$Co

| Dosage Treatment (Gy) | One seed pod (fruit) | Two-seed pods (fruit) | Three-seed pods (fruit) |
|---|---|---|---|
| 0 | 2,52 | 7,13 | 1,81 |
| 100 | 2,25 | 7,42 | 2,08 |
| 200 | 2,35 | 6,73 | 1,83 |
| 300 | 2,31 | 5,21* | 1,77 |
| 400 | 2,02 | 4,60** | 1,46 |
| 500 | 2,10 | 4,38** | 1,58 |

The variable number of seeds per pod produced by each dose of 60Co gamma ray irradiation showed that pods containing 2 seeds were the highest average. While on average, pods contain 1 seed, each treatment is more than pods containing 3 seeds. The mean value of pods containing 2 seeds at each treatment showed a marked difference at doses of 300 Gy and very noticeable differences at doses of 400 Gy and 500 Gy. At treatment doses of 100 - 500 Gy the number of pods containing 1 had lower values compared to controls. However, at a dose of 100 Gy, the number of pods containing 2 and 3 showed higher mean values compared to controls.

Table 8. Shows the number of seeds per pod of edamame plants has differences at each treatment dose. Each plant (including controls) had more 2-seed pods than 1-seed and 3-seed pods. The highest number of pods containing 2 seeds was found at a dose of 100 Gy of 7.42, while the lowest number of pods containing 2 seeds was found at a dose of 500 Gy of 4.38. The absence of empty or unfilled pods indicates that pod filling in edamame plants is running optimally (Figure 4.4). This is in accordance with the statement of Anggraito and Pukan (2015), who said that with a smaller number of pods, the filling of pods will be more optimal because there are fewer sinks (seed stockpiles), on the contrary, plants with excess pods will divide the pile evenly so that the number of seeds that can be harvested is less.

Kuswantoro (2017), in his research, stated that differences in plant diversity and seed yield are influenced by genotype traits that have different adaptability even though they grow in the same conditions. Changes that occur in 3 characters (number of pods, weight of 100 seeds, and number of seeds per pod) in the Ryoko variety edamame plant are the result of genetic diversity caused by $^{60}$Co gamma ray radiation. Changes in growth factors and production factors caused still have different variations with control plants (not irradiated), so they still require selection tests in the M3 generation and so on. Soeranto (2011) stated that mutations may not be directly expressed in phenotype, which is if the mutation occurs in a recessive direction and is in the heterozygous genotype structure or, also called, a silent mutation.

### *4.4 Standard Deviation*

Standard deviation values in edamame plant diversity are a statistical measure used to evaluate how far the values in a data set vary from their mean. In the context of plant diversity, standard deviation is used to measure the extent of genetic or phenotypic variation among individual plants in a population. Standard deviation values on the variables of plant height, number of leaves, number of branches, flowering age, harvest age, and number of pods of edamame plants of the Ryoko variety are shown in Table 9

**Table 9.** Standard deviation value on variable plant height, number of leaves, number of branches, flowering age, Harvest Age, and number of pods of edamame plants Gamma Ray Irradiation Results $^{60}$Co

| Dosage Treatment (Gy) | Standard Deviation | | | | | | |
|---|---|---|---|---|---|---|---|
| | Plant Height | Number of leaves | Number of Branches | Flowering age | Harves t age | Number of pods | Heavy 100 seeds |
| 0 | 6,53 | 6,36 | 1,16 | 1,80 | 3,73 | 5,67 | 0,83 |
| 100 | 7,14 | 6,40 | 1,17 | 1,96 | 3,97 | 3,95 | 2,07 |
| 200 | 6,31 | 5,92 | 0,94 | 1,39 | 2,97 | 5,52 | 1,31 |
| 300 | 6,00 | 4,87 | 0,95 | 1,58 | 2,62 | 5,76 | 1,28 |
| 400 | 5,30 | 4,23 | 0,68 | 1,54 | 2,81 | 5,34 | 3,40 |
| 500 | 4,01 | 4,19 | 0,65 | 1,49 | 2,82 | 6,68 | 2,03 |

Table 9 shows that the results of $^{60}$Co gamma ray irradiation have an effect on the standard deviation value. The height parameter of edamame plants has the highest standard deviation value at the 100 Gy dose treatment with a value of 7.14. The parameter of the number of leaves of edamame plants has the highest standard deviation value at the dose treatment of 100 Gy with a value of 6.40. The parameter of the number of branches of the edamame plant has the highest standard deviation value at the dose treatment of 100 Gy with a value of 1.17. The flowering age parameter of edamame plants has the highest standard deviation value at a dose treatment of 100 Gy with a value of 1.80. The harvest age parameter of edamame plants has the highest standard deviation value at the 100 Gy dose treatment with a value of 1.97. The parameter of the number of pods of edamame plants has the highest standard deviation value at the 500 Gy dose treatment with a value of 6.68. The weight parameter of 100 edamame seeds has the highest standard deviation value at the 400 Gy dose treatment with a value of 3.40. Varying standard deviation values indicate that 60Co gamma-ray irradiation exerts different effects on each plant treatment. This is indicated by a high standard deviation value that occurs not only at one radiation dose but also at different doses.

Standard deviation in plant breeding is one of several statistical measures that can be used to describe plant diversity. Standard deviation measures and increases genetic diversity that can increase plant resistance to environmental change or disease. A high standard deviation value indicates large variation, while a low value indicates more limited variation. In the observed parameters, edamame soybean plants treated with $^{60}$Co gamma ray radiation have the highest standard deviation value, showing a large variation in each plant. This was shown by the presence of a marked difference in plant height at the treatment dose of 200 Gy with the control. On the leaf count parameter, the edamame soybean plant treatment dose of 400 Gy showed a marked difference from the control. This is in accordance with the opinion of Trustinah and Iswanto (2013), who states that the higher the value of diversity, the greater the chance of obtaining a better plant genotype through selection.

### *4.5 Genetic Diversity and Heritability of Edamame Plant Generation M2*

The results of gamma ray irradiation of $^{60}$Co Generation M2 have an impact on the genetic diversity of edamame plants Generation M2. Edamame variety Ryoko generation M2 shows a diverse phenotype in each individual. This is due to the interaction between genetic and phenotypic factors. Determination of the value of genetic diversity and heritability in Ryoko variety edamame plants is important to be done as a genetic parameter, which can provide information about the magnitude of genetic influence on the phenotype of M2 generation characters of Ryoko variety edamame plants. The value of the genetic diversity coefficient is calculated first after genetic variety ($\sigma^2$e) and phenotype variety ($\sigma^2$g). The agronomic characters of edamame plants of the Ryoko variety are presented in Table 10

**Table 10.** Value of genetic diversity ($\sigma^2$g) and heritability ($h^2$) agronomic characters of generation M2 edamame plant variety Ryoko

| Character | Letter±SD | $\sigma^2$g | $\sigma^2$p | KKG | Heritability ($h^2$) |
|---|---|---|---|---|---|
| Plant Height (cm) | 28,27±5,02 | 1.174,26 | 26,19 | 10,74 | 44,84 |
| Number of Leaves | 8,02±1,58 | 94,70 | 3,40 | 5,73 | 27,84 |
| Number of Branches | 2,47±0,47 | 16,37 | 5,72 | 4,29 | 2,86 |
| Number of pods | 7,66±1,58 | 38,33 | 1,76 | 4,57 | 21,80 |
| Flowering age | 32,87±5,37 | 48,62 | 1,47 | 4,26 | 33,16 |
| Umur Panen | 109,47±8,96 | 68,25 | 73,26 | 4,92 | 93,00 |
| Weight 100 Seed | 42,37±4,21 | 116,41 | 21,62 | 7,31 | 5,38 |

Remarks: SD = Standard deviation; KKG value <25% = low, Heritability >50% = high, 20 %< h2>50% = medium, and $h^2$ <20% = Low.

Based on the data in table 10 shows that Generation M2 edamame plants of the Ryoko variety grown in lowland areas have different genetic diversity values in each agronomic character observed. The value of the coefficient of genetic diversity in these characters ranges from 4.29% - 10.74%. The range of genetic diversity values in all edamame characters in this study had low criteria. The results of the heritability value analysis based on table 10 show that the results of $^{60}$Co gamma ray irradiation on 7 characters observed show that the harvest age character is the character that has the highest haritability value. While the number of branches character is the character with the lowest heritability value compared to the other 5 characters.

The results of $^{60}$Co gamma ray irradiation affect the genetic diversity of Generation M2 edamame plants, with the emergence of diverse phenotypes in each individual. Generation M2 edamame plants of the Ryoko variety grown in lowland areas have different genetic diversity values in each agronomic character observed. The value of the coefficient of genetic diversity in these characters ranges from 4.29% - 10.74%. The range of genetic diversity values in all edamame characters in this study had low criteria (Table 4.10). The results of research conducted by Nilahayati and Putri (2015) reported that the value of genetic diversity in soybean plants of red fan varieties, gamasugen-1, Muria, Mitani, and Mutiara 1 ranged from 6.55-42.31%, which was analyzed based on the value of genetic diversity coefficient (KKG) on 12 agronomic characters. Based on the data presented in Table 10, the tall character of the M2 generation edamame plant of the Ryoko variety has a genetic diversity coefficient value of 10.74%, so the value of the genetic diversity coefficient in the height of the edamame plant is relatively low.

In Arwin's opinion (2015), agronomic characters that appear in plant height parameters have an important role in supporting the success of soybean cultivation. The high character of plants with high genetic diversity values can be the target of selection to obtain edamame plants with a posture that is not too high and has a sturdy stem structure so as to increase plant resistance to dryness and minimize the risk of crop failure. In this study, low genetic diversity indicates that individuals in the population tend to be uniform. This is supported by research conducted by Hapsari (2016), which states that the more diverse the individual traits in a population, the higher the frequency of genes desired, while low genetic diversity indicates that individuals in the population tend to be uniform.

The results of $^{60}$Co gamma ray irradiation affect the character of the number of leaves of the M2 generation edamame plant by showing a diversity coefficient value of 5.73% (Table 10). The value of the coefficient of genetic diversity in the number of leaves is low. The low value of the genetic diversity coefficient on the character of the number of leaves indicates that the number of leaves owned by each individual of edamame plants in the population tends to be uniform, and only 5.73% of all individuals in the population are diverse. Research conducted by Purba et al. (2013) reported that the low genetic diversity in a character can also be caused by irradiation treatment on its elders, which has not been able to increase diversity or the influence of very high environmental factors. Sibarani et al. (2015) in his research stated that the effect caused by gamma ray iradias 60Co can cause a decrease in the number of leaves and can change the shape of the leaves from ovoid (normal) to elongated and thicker, and there are unifoliate and bifoliate leaves.

The results of $^{60}$Co gamma ray irradiation affect the character of the number of branches of the M2 generation edamame plant by showing a genetic diversity coefficient value of 4.29% (Table 10). The value of the coefficient of genetic diversity in the number of branches is low. The low value of the coefficient of genetic diversity indicates that only 4.29% of the characters number branches in individuals in diverse populations. The results of $^{60}$Co gamma ray irradiation affect the character of the number of pods of the M2 generation edamame plant, with a genetic diversity coefficient value of 4.57%. The low value of the genetic diversity coefficient on the character of the number of pods indicates that the number of pods in each individual of edamame plants in the population tends to be uniform, and only 4.57% of all individuals in the population are diverse.

The results of $^{60}$Co gamma ray irradiation affect the weight character of 100 seeds of the M2 generation edamame plant. The value of the genetic diversity coefficient at the weight of 100 seeds showed a diversity of 7.31%. The value of the coefficient of genetic diversity at the weight of 100 seeds is relatively low. The low value of the genetic diversity coefficient shows that the weight of 100 seeds owned by each individual of edamame plants in the population tends to be uniform, and only 7.31% of all individuals in the population are diverse. The results of $^{60}$Co gamma ray irradiation affect the character of flowering age and harvest age of M2 generation edamame plants. The value of the genetic diversity coefficient at flowering age showed a diversity of 4.26%, while the harvest age character showed a diversity of 4.92%. The value of the coefficient of genetic diversity at the flowering age and harvest age of edamame plants is relatively low.

The flowering age of edamame plants was observed after 80% of the 288 plants in the flowering population, and how many days the plant reached 80% flowering was noted. While the harvest age of edamame plants was observed after 90% of the 288 plants in the physiological ripening population, which were characterized by yellowing leaves, and some had begun to wither and fall off, and pods were already dark brown. To get a genjah-aged edamame plant, very important selection criteria are flowering age and harvest age (Arwin, 2015). Selection of each character in this study cannot be done because the characters in each individual tend to be uniform. This is in accordance with the opinion of Nilahayati & Putri (2015) that genetic diversity greatly affects selection activities; if a character has a high genetic diversity value, then selection can be carried out, but if the value of genetic diversity is low, then selection activities cannot be carried out. This is because individuals in the population are relatively uniform.

The heritability value based on table 10 shows that the results of $^{60}$Co gamma ray irradiation show that the harvest age character is the character that has the highest heritability value. While the number of branches character is the character with the lowest heritability value compared to the other 5 characters. Heritability value is a genetic parameter used to measure the ability of a genotype in a plant population to pass on its characters or estimation to measure the extent to which the phenotype in the edamame plant population of the Ryoko variety in the M2 generation is influenced by genetic factors.

Based on the data presented in table 10, it shows that the highest heritability value is found in the harvest age character, which is 93%, followed by plant height character, flowering age, number of pods, and number of leaves, respectively 44.84%, 33.16%, 21.80%, and 27.84%. The lowest heritability value is found in the character of the number of branches, amounting to 2.86%. Agronomic characters of harvest age (93%) have heritability values with high criteria, while plant height characters (44.84%), flower age characters (33.16%), leaf count characters (27.84%), and number of pods (21.80%) have medium heritability criteria. The character of the number of branches (2.86%) and weight of 100 seeds (5.38%) are grouped into low heritability criteria. The high heritability value shows that genetic influences have a greater role in the harvest age of edamame plants. This is supported by research conducted by Purba et al. (2013), that the amount of high heritability value shows that genetic factors have a greater influence than environmental factors.

The heritability value with medium criteria indicates that the influence of environmental factors is as great as the influence of genetic factors, while the heritability value with low criteria indicates that the variability caused by environmental factors is greater than the genetic variability. Heritability values in edamame plants of the M2 generation Ryoko variety are in the low to high range. Heritability value is a benchmark used to make a selection because it is influenced by genetic factors that are easy to pass on to the next generation. The greater the heritability value produced, the faster the progress of selection and formation of high-yielding varieties will be. If the heritability value is lower, the selection process will be smaller, and the formation of high-yielding varieties will take longer. According to Syukur (2012), heritability is a comparison between the magnitudes of genetic variety with the total amount of phenotype variety of a character. The relationship between the magnitude of genetic variety and the total amount of phenotype variety illustrates how far the phenotype appears to be a reflection of genetic factors. Genetic diversity and the amount of heritability value are very useful for determining genetic progress obtained through the selection stage. High genetic diversity and heritability are prerequisites for effective selection. While the high heritability value shows that there is variation in phenotype mostly caused by genetic diversity so that selection will obtain genetic progress and have a high chance of being passed on to offspring (Nilahayati and Putri, 2015).

### *4.6 The Effect of $^{60}Co$ Gamma Ray Irradiation Results on Edamame Protein Levels*

The results of $^{60}Co$ gamma ray irradiation affect the levels of edamame protein Generation M2. Protein levels in edamame seeds decreased at doses of 200 Gy, 300 Gy, 400 Gy, and 500 Gy (Table 11). The average amount of the highest protein content is indicated at the 100 Gy dose, and the lowest average is shown at the 500 Gy dose. The protein content of edamame seeds at a dose of 100 Gy had good results compared to other dose treatments but did not show a difference with the dose of 0 Gy (Control). This suggests that irradiation does not induce mutations that lead to increased levels of the protein.

**Table 11.** Results of $^{60}Co$ gamma ray irradiation on the protein content of edamame

| Dosage Treatment (Gy) | Protein Up |
|---|---|
| 0 | 18,05 g |
| 100 | 18,05 g |
| 200 | 17,13 g |
| 300 | 17,01 g |
| 400 | 16,35 g |
| 500 | 16,12 g |

The data presented in Table 11 show the effect of $^{60}Co$ gamma ray irradiation results that can reduce protein levels in edamame crops in the M2 generation. The results of testing protein levels show a decrease along with the increase in irradiation dose caused by free radicals formed during the irradiation process. This is caused by free radicals formed during the irradiation process due to the high moisture content of edamame seeds. These free radicals can damage or modify plant cell components, thus affecting chemical and biological processes that may be vital to the survival of organisms (Marcu et al., 2013).

The protein content of edamame seeds at a dose of 100 Gy had the highest protein content but showed no difference with the dose of 0 Gy (Control). This suggests that irradiation does not induce mutations that lead to increased levels of the protein. Physically, protein levels can affect the physical resistance of cells when receiving gamma ray radiation. This is related to the water content that a seed has when radiation is given. Water content in cells that receive gamma ray radiation will produce free radicals that collide in various directions so that they can cause changes or mutations both at the DNA level, cell level, and tissue (Rahmawati, 2009). Edamame seeds contain as much as 10% moisture content. The more oxygen and water molecules (H2O) in the irradiated material, the more free radiation will be formed so that plants become more sensitive (Herison et al., 2008). Nur and Syahruddin (2015), in their research, stated that high doses of $^{60}Co$ gamma ray irradiation cause damage to the structure and components of genetic material. It can alter synthetic proteins and plant metabolic systems and can be observed in plant growth characters.

### *4.7 Effects of $^{60}Co$ Gamma Ray Irradiation on Edamame Growth and Yield in Lowlands*

In general, the productivity of edamame plants is determined by genetic characters and environmental factors. Potential yields on edamame plants can be achieved if, during the growing period, the plant does not experience interference with biotic and abiotic factors, especially if the disturbance occurs at the time of pod formation until seed development. Based on the magnitude of the standard deviation value in edamame plants generation M1 and generation M2, the results of gamma ray irradiation $^{60}Co$ did not show a different effect on plant height, and the number of leaves of edamame plants, both planted in lowland and highland areas. However, it has an influence on the number of filled pods produced.

**Table 12.** Standard Deviation Yield of Edamame Generation M1 and M2 Plants

| Dosage Treatment (Gy) | Plant Height | | Number of leaves | | Number of pods | |
|---|---|---|---|---|---|---|
| | M1 | M2 | M1 | M2 | M1 | M2 |
| 0 | 6,46 | 6,53 | 1,23 | 1,16 | 9,02 | 5,67 |
| 100 | 7,01 | 7,14 | 1,19 | 1,17 | 12,69 | 3,95 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 200 | 6,66 | 6,31 | 0,84 | 0,94 | 8,7 | 5,52 |
| 300 | 6,1 | 6,00 | 0,93 | 0,95 | 8,8 | 5,76 |
| 400 | 4,98 | 5,30 | 0,68 | 0,68 | 10,67 | 5,34 |
| 500 | 4,03 | 4,01 | 0,67 | 0,65 | 8,92 | 6,68 |
| **Total** | **35,24** | **35,29** | **5,54** | **5,55** | **58,80** | **32,92** |

Description: M1 Generation data is taken from previous research (Fatma et al., 2023) in Lawang Area, Kab. Malang, ± 485-560 mdpl

The productivity of edamame plants is determined by genetic characters and environmental factors. The potential yield of a plant can be achieved if, during the growing period, the plant does not experience interference with biotic and abiotic factors, especially if the disturbance occurs at the time of pod formation until seed development (Sumadi, 2000). Too high a temperature in the reproductive phase results in a decrease in edamame yield (Isoda et al., 2010). Thus, to achieve the yield potential of each cultivar, attention must be paid to the level of suitability of the land and climate as well as the application of cultivation technology. The level of land suitability for soybeans varies from very suitable to not suitable. The number of edamame pods planted in lowlands has a lower yield potential compared to the number. The results of the Sumadi experiment (2000) concluded that the weight of seeds per plant was influenced by the number of pod contents by 37.2%, while the weight of 100 grains only 13.7% affected the weight of seeds per plant. Ryoko variety edamame grown in the lowlands yields lower, although the seed size is larger than edamame cultivated in highland areas.

Tambunan and Afkar (2019) stated in their research that the height of different places causes differences in the flowering age and harvest age of edamame plants. Edamame plants planted in the lowlands (±10 masl) have the opportunity to have a more mature age higher plants than soybeans planted in the highlands (>500 masl). Temperature affects physiological processes, so it has an impact on the flowering age and maturity of seeds (Sumadi et al., 2017). Although generally, edamame is only able to grow well in highland areas, based on research by Hakim (2013) states that the protein content of seeds and the number of leaves of edamame plants do not differ between seeds produced in the highlands and those produced in the lowlands. The results of his research showed that edamame seeds produced in the highlands and lowlands produced the same number of leaves in young edamame plants. The number of young edamame leaves is not influenced by height but is predominantly determined by the genetic properties of the plant. On the other hand, (Agung and Rahayu, 2004) in their research argued that the use of solid organic fertilizers and the use of biological fertilizers could increase the growth and production of edamame in the lowlands. Bioorganic fertilizer can increase nutrient absorption efficiency, improve growth, increase plant production components, and increase plant physical resistance to pests and diseases.

## 5. Conclusion

The results of gamma 60Co ray irradiation show that there are high criteria for genetic diversity values in all agronomic characters of the M2 generation of Ryoko variety edamame plants, while in the heritability values, high criteria heritability values are found for the characters of harvest age, plant height and flowering age.

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