Effect of gamma irradiation dosage on green bean growth and yield

Supanjani Supanjani[1], *Satria* Alexander[1], and *Nanik* Setyowati[1*]

[1]Department of Crop Production, Faculty of Agriculture, University of Bengkulu, WR. Supratman street, Kandang Limun, Kota Bengkulu 38371, Indonesia

Abstract. Gamma radiation is a particular approach for increasing green bean (*Vigna radiata* L.) growth and yield. Gamma radiation at the appropriate dose enhances plant growth and yield. The research attempts to determine the proper dose of gamma radiation on the growth and yield of green beans. The research was carried out at Talang Kering, Muara Bangkahulu, Bengkulu, Indonesia. The design employed was a Complete Randomized Block Design (RCBD) with two factors. The first factor was the green bean variety, consisting of Vima-1 and Vima-4. The second factor was the radiation dose, which was 0, 50, 100, 200, 400, or 800 Gy. The data were analyzed using the F-test with a 5% significant level and further tested using the Duncan Multiple Range Test (DMRT) at a 5% level. The study's findings revealed that gamma irradiation of up to 800 Gy on green bean seeds resulted in higher plant height, number of pods, number of seeds/plants, and seed weight/plant. The Vima-1 variety of green beans produced a higher weight of 100 seeds when irradiated with gamma rays at 100 Gy, while the Vima-4 variety at a dose of 200 Gy. These findings provide valuable insights for optimizing green bean cultivation practices.

1 Introduction

Green beans (*Vigna radiata* L.) are potential agricultural commodities for the food diversification in Indonesia. The public consumes green beans, considering these beans are high in protein, vitamins, and minerals, all essential for human nutrition. The nutritional content in 100 g green bean is 323 calories, protein 23 g, fat 1.5 g, carbohydrates 56.8 g, calcium 223 mg, vitamin C1 10 mg, and water 15.5 g [1]. Factors affect bean production, include Soil Quality, Climate, Watering, Pests and Diseases, Cultivar Selection, Agricultural Practices and Irradiation Techniques.

Green beans are an adaptable plant in various warm (tropical) regions. Green beans adapt to Indonesia's lowlands, up to 500 meters above sea level. Green beans grow in an environment with temperatures ranging from 25 °C to 27 °C, air humidity of 50% to 80%, monthly rainfall of 50 mm to 200 mm, and adequate sunlight [2]. The national average green bean yield is 1.0 - 1.2 tons/ha [3], lower than the potential yields of green bean varieties Vima 1 (1.76 tons/ha) and Vima 4 (2.32 tons/ha) [4]. Gamma ray radiation is a technology that can be used to increase crop yields.

* Corresponding author: nsetyowati@unib.ac.id

Gamma irradiation is a radiation technology that could enhance green bean productivity by increasing their growth and yields. It is reported that gamma irradiation at the appropriate dose affects plant growth and yield of Jerusalem artichoke (*Helianthus tuberosus*) [5], common bean (*Phaseolus vulgaris* L.) [6], gladiolus (*Gladiolus grandiflorus*) [7], eggplants (*Solanum melongena*) [8] including green bean [9].

Gamma rays have a high penetration power and uniform deep penetration [10], 2008). Research on upland rice plants of the red Sigambiri variety with doses of 0 Gy, 100 Gy, 200 Gy, 300 Gy, 400 Gy, 500 Gy, 600 Gy, 700 Gy, 800 Gy, 900 Gy, and 1000 Gy revealed that the most effective dose of gamma irradiation for red Sigambiri is 200 Gy. Upland rice germination percentage, seedling height, root length, and percentage of empty panicles are lower at 200 Gy compared to higher dosages [11]. According to [12], gamma ray irradiation of Brast-1 red beans at doses of 55 Gy, 110 Gy, 165 Gy, and 220 Gy resulted in several quantitative and qualitative trait modifications. Gamma irradiation considerably affected the unsaturated to saturated total fatty acid and total hydrocarbon to sterol ratios in soybean, peanut, and sesame seed oils [13]. When exposed to 55 Gy of gamma radiation, the red beans produced a greater weight of 100 grains and more flowers than in other treatments. Leaf morphology and pod features are indications of qualitative character changes.

Other studies show that gamma irradiation on green beans under drought conditions with doses of 0 Gy, 100 Gy, 200 Gy, and 300 Gy had a significant effect on harvest age, root volume, number of pods/plants, and seed weight/plant [14]. Gamma radiation at doses of 0 Gy, 100 Gy, 150 Gy, and 200 Gy in black soybeans has been reported to affect germination %, plant height, and harvest age [15]. The Anjasmoro soybean variety responds positively to gamma radiation regarding flowering time, harvest time, seed/plant weight, and seed/plant quantity. The most effective irradiation dose was 200 Gy [16].

The experiment on the effect of gamma irradiation dosage on green bean growth and yield is essential for advancing agricultural productivity. Gamma irradiation, a method used to induce mutations, can significantly enhance plant characteristics such as height, pod number, seed number, and seed weight. Understanding the optimal dosage is crucial, as it varies across different green bean varieties and can maximize crop yield and quality. This technique aligns with the goals of sustainable agriculture by potentially reducing the need for chemical inputs and improving crop resilience. This study aimed to determine the most effective dose of gamma irradiation for green bean plant growth and yield. Finding the effective dose of gamma irradiation for green bean plant growth and yield has significant implications for agriculture. This can lead to increased productivity and efficiency in green bean cultivation, potentially reducing the need for chemical inputs and enhancing crop resilience. Moreover, it supports sustainable agricultural practices by improving yield and quality, which is crucial for meeting the growing food demands and addressing food security challenges.

2 Materials and Methods

2.1 Plant materials and experimental design

Field research was conducted in Talang Kering Village, Muara Bangkahulu District, Bengkulu, Indonesia on April - June 2022. The experimental design was a Randomized Complete Block Design (RAKL) with two factors. Factor 1 was green bean variety (V), including Vima 1 and Vima 4 varieties. Factor 2 was Gamma radiation dose (D): D0 = 0 Gy, D1 = 50 Gy, D2 = 100 Gy, D3 = 200 Gy, D4 = 400 Gy, and D5 = 800 Gy. There were 12 treatment combinations, each of which was repeated three times.

The tested seeds were green bean cultivars Vima 1 and Vima 4, certified by BALITKABI, Malang, East Java, Indonesia. The gamma irradiation process was carried out at BATAN in

Jakarta, Indonesia. Irradiation was performed by placing the seeds in the chamber of the gamma cell 220 device, Cesium-137 or Cobalt-60 by Nordion. The gamma cell 220 apparatus operates on a Cobalt-60 energy source with a 1.55 Gy/second dosage rate. The seedlings were subsequently subjected to gamma rays at specified doses: 50, 100, 200, 400, and 800 Gy.

The experiment used a plot measuring 1 m x 1.5 m (length x width), with a distance of 30 cm between plots and 50 cm between blocks. Seeds are placed approximately 3 cm below the soil surface. Two seeds were planted in each planting hole and 5 granules of carbofuran was inserted into the hole, then covered with soil. Thinning was carried out 2 weeks after planting (WAP). The planting distance of green beans was 40 cm by 15 cm.

Fertilizer was applied at 2 WAP and 6 WAP. Urea at a dose 50 kg/ha, SP36 at 40 kg/ha and KCl at 20 kg/ha were applied at 2 WAP while 30 kg/ha of urea, 20 kg/ha of SP36, and 40 kg/ha of KCl at 6 WAP. The fertilizer was inserted in the planting hole 10 cm from the stem. Grasshoppers (Caelifera) and caterpillars (*Chrysodeixis chalcites*) were chemically controlled with an insecticide containing the active ingredient Fipronil at a concentration of 1 ml/L and a concentration of 50 g/L. Fungus *Cercospora sinensis* was controlled using a fungicide containing 2 g/L of the active ingredient 63% mancozeb.

2.2 Observation

Green beans were harvested when the pods reached maturity, conforming the criteria of black pod, at 57 days after sowing. Observation data comprised of plant height (cm), branches number, leaves number, leaves greenness, shoot dry weight (g), pods number /plant, seeds number/plant, seeds weight/plant, and the weight of 100 seeds.

2.3 Data analysis

The observed data was analyzed with an analysis of variance (F test) at a 5% significance level. Separation of treatment means used Duncan Multiple Range Test (DMRT) at the 5% level.

3 Results

3.1 Variance analysis

Table 1 summarizes the F results of tests at the 5% level for all variables. The gamma irrigation treatment and green beans cultivars affected the weight of 100 seeds. The green beans growth did not differ among cultivars used in this study. Meanwhile, the dose of gamma irradiation significantly influenced plant height, number of branches, number of leaves, leaf greenness, number of pods, number of seeds per plant, and weight of seeds per plant.

3.2 Green bean yield under different variety

The Vima-1 and Vima-4 varieties yielded a similar yield of green beans such as pod number, seeds per plant, seed weight, and weight per 100 seeds (Table 2). Generally, the average number of pods and the number and weight of seeds for green bean varieties Vima-4 are slightly higher than Vima-1. The Vima-4 green bean seeds are larger than those of the Vima-1 cultivar, weighing 6.75 g per 100 seeds (Tabel 2).

Table 1. Effect of gamma ray irradiation dose on growth and yield of green beans

Variables	F -value				CV (%)
Growth Component	**Block**	**Interaction**	**Variety**	**Dose**	
Plant height	0.30 ns	1.23 ns	2.11 ns	6.30 *	16.19
Branch number	1.78 ns	1.30 ns	1.94 ns	24.22 *	11.23
Leave number	2.01 ns	1.20 ns	2.25 ns	24.02 *	11.07
Leaves greeness	0.39 ns	0.41 ns	0.12 ns	5.27 *	5.17
Shoot dry weight	2.82 ns	0.18 ns	0.28 ns	1.30 ns	16.96
Yield component					
Pod number	1.24 ns	0.74 ns	0.51 ns	5.45 *	18.81
Seeds number/plant	0.97 ns	0.98 ns	1.00 ns	4.78 *	18.34
Seed weight/plant	0.14 ns	0.74 ns	1.28 ns	8.47 *	17.82
100 seeds weight	0.51 ns	3.16 *	0.42 ns	1.88 ns	2.54

Note: * = significantly different (5%), ns = no significant effect, CV (Coefficient of Variation).

Table 2. Comparison of yield components of green bean varieties Vima-1 and Vima-4.

Variety	Pod number	Seed number	Seed weight (g/plant)	100 seed weight (g)
Vima -1	8.0	84.25	5.11	6.71
Vima -4	8.3	89.58	5.46	6.75

3.3 Effect of gamma ray irradiation dosage on growth and yield of green beans

The dose of gamma irradiation significantly affected plant height, number of branches and leaves, and leaf greenness, but not on shoot dry weight (Table 3).

Table 3. Effect of gamma irradiation dose on green bean growth components

Dose	Plant height (cm)	Branch number	Leaves number	Leaves greeness	Shoot dry weight (g)
0 Gy	21.38 ab	5.66 a	17.03 a	53.62 a	1.81
50 Gy	22.36 a	5.70 a	17.11 a	53.58 a	1.78
100 Gy	21.34 ab	5.33 a	15.96 a	52.00 a	1.82
200 Gy	25.19 a	5.66 a	16.98 a	51.66 ab	1.93
400 Gy	17.87 bc	3.80 b	11.41 b	48.53 bc	1.59
800 Gy	15.53 c	3.2 b	9.76 b	47.81 c	1.58

Note: Numbers followed by different letters show significant differences in the DMRT 5% test.

Each treatment of gamma doses resulted in a different growth rate for green beans, although exhibiting a similar growth trend. Fig. 1A and 1B show the growth pattern of the influence of irradiation dose on plant height and the number of leaves at 2, 3, and 4 WAP.

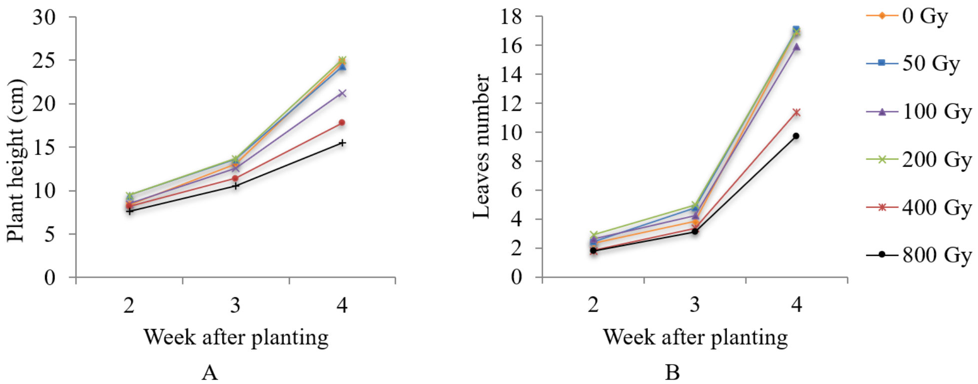

Fig. 1. Effect of gamma ray dose on green bean height and leaves number.

Plant height and shoot dry weight tend to increase with increasing doses of gamma radiation up to 200 Gy. Plant height, the number of branches, the number of leaves, leaf greenness, and shoot dry weight were decreased as the gamma irradiation increased above 200 Gy (Table 3). The plant height and the number of green bean leaves increased weekly from 2 WAP to 4 WAP at all irradiation dosages, and green beans exposed to 800 Gy of gamma radiation produced the shortest plant height and the fewest leaves (Fig. 1A and 1B).

3.4 Effect of gamma ray irradiation dosage on green bean yield

Table 4 shows the effect of gamma irradiation dose on the yield of green beans. The dose of gamma irradiation significantly affected green beans' yield components, including the number of pods, seed number per plant, and seed weight per plant. Still, it had no significant effect on the weight of 100 seeds (Table 4).

Table 4. Effect of gamma irradiation dose on green bean yield

Dose	Pod number	Seed number	Seed weight (g/plant)	100 seed weight (g)
0 Gy	9.43 a	98.10 a	6.17 ab	6.63 b
50 Gy	8.50 ab	89.03 ab	5.36 b	6.74 ab
100 Gy	8.56 ab	90.03 ab	5.42 b	6.90 a
200 Gy	9.73 a	103.36 a	6.76 a	6.76 ab
400 Gy	5.96 c	64.83 c	3.98 c	6.67 b
800 Gy	6.90 bc	76.16 bc	4.02 c	6.70 ab

Note: Numbers followed by different letters are significantly different in the 5% DMRT Test.

Green beans irradiated with gamma rays at 200 Gy produced the most pods and seeds per plant, with an average of 9.73 pods and 103.36 seeds (Table 4). Increasing the gamma radiation above 200 Gy decreased the number of pods and green bean seeds harvested.

4 Discussion

Gamma irradiation dose influences green bean growth and yield. Green bean growth and yield did not differ significantly between gamma dosages ranging from 50 to 200 Gy. Increasing the dose of gamma rays above 400 Gy reduces green bean productivity compared to 200 Gy or lower doses. While green bean seeds irradiated with 200 Gy, the plant height, number of pods, number of seeds planted, and seed weight per plant increased compared to other dose treatments (Table 3).

Several other studies have shown that a 200 Gy irradiation dosage can accelerate growth in legume cover crops [17], increase the weight of Anjasmoro variety soybean seeds [16], and improve germination percentage, seed height, and rice root length [11], whereas 220 Gy of gamma irradiation enhanced the number of pods, seed weight per plant, and weight of 100 red bean seeds [12]. [1] reported that the optimal dose of irradiation for soybeans is 263 Gy to 343 Gy, using gamma rays to increase the biological effects of the M1 generation, including changes in survival rate, yield, and fertility of soybeans. The low gamma doses, particularly the 200 Gy dose, contributed to the improvement of the morphological and agronomical properties of the wheat, including spike length, 1000 grain weight, and grain yield [18]. Thus, treatment with irradiation dosages of up to 200 Gy impacts plant growth and yield.

Gamma irradiation affects plants because it acts as a stress signal and stimulates stress responses by increasing the synthesis of polyphenolic acids, antioxidants that benefit plant growth and yield [19]. The seed has essential growth components and energy for initial growth. Irradiation at low doses (< 200 Gy) on seed activates enzymes and develops young embryos, stimulating cell division. This cell division process promotes not only germination but also vegetative growth and plant yield [20].

In line with this research, the results of other studies show that a dose of gamma irradiation between 300 Gy - 400 Gy reduces the growth of Mucuna pruriens L. seeds [21], and a dose of 400 Gy reduces almost all agronomic and morphological traits of soybeans, including plant height.

[22] reported a decrease in the germination percentage in Kipas Putih soybean seeds at 200 Gy, reaching 50% on the fourteenth day after planting. Irradiation dosages of 400 and 600 Gy diminish the germination percentage to 20% and 30%, respectively. At doses of 800 and 1000 Gy, all seeds died on the 21st day after planting.

The adverse effects of high-dose gamma irradiation are caused by radiation exposure to biological systems, which triggers a series of chemical and physical reactions beginning with energy absorption and ending with biological damage. Furthermore, the excitation and ionization events produce ionized water molecules and free radicals. These free radicals harm or alter plant cell components, disrupting chemical and biological processes that may be crucial to plant survival [23]. Gamma irradiation of seeds at high doses disrupts protein synthesis, hormone balance, gas exchange, water exchange, and enzyme activity, causing disturbances in plant morphology and physiology as well as inhibiting plant growth and development [24], resulting in decreased green bean growth and yield.

5 Conclusions

Gamma irradiation dose influences green bean growth and yield. Gamma irradiation at a dose of 200 Gy increased the average plant height, number of pods, number of seeds per plant, and seed weight per plant compared to lesser doses. Gamma dosages ranging from 400 to 800Gy have a detrimental impact on soybean growth and yield. Both varieties of green beans, Vima-1 and Vima- have similar response to gamma irradiation. This finding lead to increased productivity and efficiency in green bean cultivation, potentially reducing the need for chemical inputs and

Further research enhancing crop resilience should focus on optimizing gamma irradiation doses between 200 Gy and 400 Gy to determine the threshold where detrimental effects begin. Expanding the study to more green bean varieties and different environmental conditions will help assess consistency and broader applicability. These efforts can enhance productivity and sustainability in agriculture by maximizing yields without adverse effects, ultimately supporting food security and agricultural resilience.

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