INDUCED MUTATION BY GAMMA RAYS IRRADIATION TO INCREASE CHILLI RESISTANCE TO BEGOMOVIRUS

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ABSTRACT

Begomovirus infection has a significant impact of lowering chilli yield in Indonesia. A constraint of narrow genetic variability of chilli in Indonesia has made the mutation breeding program as a solution worth-pursuing in increasing the genetic variability. The objective of this study was to determine the LD50 point for each of the five irradiated chilli genotypes and the optimum dose of gamma irradiation in inducing chilli resistance to Begomovirus and other improved agronomical traits. The study was conducted in the Indonesian Vegetable Research Institute (IVEGRI) at Cikole-Lembang, elevation 1,200 m above sea level, from March to December 2013. Split plot design was used with genotype as main factor (Kencana, Lembang-1, SSP, Tanjung 2, Seloka) and irradiation dosage as sub-factor (0, 200, 400, 600, 800 Gy). All treatments were replicated three times. The results showed that LD50 points of the five irradiated chilli genotypes were in the range of 422.64-629.68 Gy. There were some chilli genotypes in the population of M2 that had high coefficient variance genetic (CVG) and broad sense heritability (h2bs) value for disease incubation time. This could be used as resistance parameter to Begomovirus and improvement parameter of several agronomical traits.

Keyword: Begomovirus; Capsicum annuum; gamma rays; induced mutation

INTRODUCTION

Begomovirus has been identified as one of important diseases that influence the yield of chilli in Indonesia. At present, Begomovirus infection had been widely spread in all chilli production centers. Bemisia tabaci is the insect vector that responsible only for the virus trans-mission, but not for virus propagation (Sulandari et al., 2004). Infected plants show bright yellow-ing or yellow-green mosaic, vein clearing, curly, and stunted leaves. Yield loss caused by this disease may reach approximately 20-100% (Setiawati, 2003).

At the farmer’s level, some control methods, such as plant eradication or insect vector chemical spraying has been applied to control the Begomovirus. However, field observations indicate that these control methods are still not effective yet. Womdim et al. (1991) suggests that the most effective and efficient control method to eliminate this disease is to use a resistant variety. Unfortunately, such variety has not been available yet in Indonesia. The germplasm genetic variability, especially for Begomovirus resistance is quite low, since Indonesia is not the center of chilli origin. Narrow genetic variability has become a constraint for chilli conventional breeding program because of the difficulty in obtaining the source for resistant genes.

Various strategies to increase chilli genetic variability can be pursued by such as seed introduction, hybridization, and mutation. Mutation seems more preferable than the other two since seed introduction sometimes may function as a media of transferring seed borne diseases, while hybridization will not be effective if there is no resistant gene available. Furthermore, conventional breeding by hybridization usually takes longer, yet sometimes also carries unexpected traits. This may result in an output.
that is not as good as expected as a commercial variety.

Mutation is one of possible alternatives to conventional breeding for crop improvement program (Soeranto, 2011). Mutation is a sudden heritable change in an organism and generally induces structural and composition changes in genome, chromosome, gene, or DNA (Soeranto et al., 2001; Dhanavel et al., 2012). Exposing plant genetic material (seed, pollen, rhizome, callus, etc.) to mutagens enhances the chance for isolating unique genetic material. Induced mutation can rapidly create the variability of inherited traits in crops, both quantitatively and qualitatively (Muduli and Misra, 2007). Post induced mutation has been effectively utilized in developing new and valuable alternation in plant characteristics that have contributed to increase yield potential or disease resistance.

One of physical mutagens in mutation breeding is gamma rays. Gamma rays belong to ionizing radiation and radiation-induced ionizations may act directly on the cellular component molecules or indirectly on water molecules, causing water-derived radicals. Since water is the major constituent of cells, the absorption of energetic radiations by water results in both excitations and ionizations leading to production of free radicals that in turn can attack other critical molecules (indirect effect). Free radicals react with nearby molecules in a very short time, re-sulting in breakage of chemical bonds or oxidation (addition of oxygen atoms) of the affected molecules. These radicals can damage or modify important components of plant cells and they have been reported to affect the morphology, anatomy, biochemistry and physiology of plants differently depending on the irradiation level (Kim et al., 2004).

Gamma rays irradiation is an efficient tool to produce mutants in crop breeding and more than 1,800 cultivars either obtained as direct mutants or derived from their crosses have been released worldwide in 50 countries (Ahlolwalia and Maluszynski, 2001). In Indonesia, gamma rays irradiation has been used in agriculture research and development since several decades ago, especially in fields of mutation breeding, pest control, plant nutrition, and animal health. In breeding program, this approach has not only contributed several crop varieties to national agriculture, but also generated hundreds of promising mutant lines that are ready for further multi-location trials. However, it is noted that no work on chilli resistance to Begomovirus has been carried out yet.

The aim of the present study is to determine the LD₅₀ point for each of the five irradiated chilli genotypes and the optimum dose of gamma irradiation in inducing chilli resistance to Begomovirus and other improved agronomical traits.

**MATERIALS AND METHODS**

The study was conducted in the Indonesian Vegetable Research Institute (IVEGRI) at Cikole-Lembang, elevation 1,200 m above sea above level, from March to December 2013. The genetic materials used were five open pollinated chilling varieties (M₀): Kencana, Lembang-1, SSP, Tanjung 2, Seloka that were all susceptible to Begomovirus. M₀ seeds used had the water content of 10-12% and the viability of 90%. Each seed variety was packed in 3 g (± 750 seeds) small plastic bag for each irradiation doses.

Gamma rays irradiation was carried out at The Center for Isotopes and Radiation Application-PATIR, Pasar Jumat, Jakarta. The seeds were subjected to gamma radiation at an irradiation dose of: 0 (control); 200 Gy; 400 Gy; 600 Gy; 800 Gy. After irradiation, the status of M₀ seeds changed to M₁ seeds automatically because the cell condition of each irradiated M₀ seed was changed and different. Then M₁ seeds were sown in the small polybag filled with media consisted of soil: humus = 1 : 1. After six weeks, seedlings were ready for transplanting in the open field.

The experimental design used was split plot with genotype as main factor, consisted of five treatments (Kencana, Lembang-1, SSP, Tanjung 2, Seloka) and gamma rays irradiation dose as sub factor, consisted of five treatments (0, 200, 400, 600, 800 Gy). All treatments were replicated three times. Land preparation was carried out thoroughly. Basal fertilizer was organic manure (30 t ha⁻¹) mixed with 100 kg ha⁻¹ of P₂O₅ applied a week before transplanting. Split fertilization was provided three times for a total of 180 kg ha⁻¹ of N and 120 kg ha⁻¹ of K₂O applied at 3, 6 and 9 weeks after transplanting (Nurtika and Hilman, 1991; Hilman and Suwandi, 1992). Beds were covered by silver plastic mulch with 40 x 60 cm planting distance. Standard crop
maintenance that includes plant protection (pesticide spraying) and irrigation (watering) was also applied. Self pollination was done on flowers of the irradiated M₁ plant within the range of LD₅₀ point to produce the M₂ seeds.

The M₂ individual seedling of each genotype was screened by using mass transfer method. B. tabaci was prepared by collecting ± 250 imago non viruliferous using an aspirator tool, then the imago was released on Begomovirus infected chilli plants for 48 hours. After that, 20-30 imago units of B. tabaci viruliferous was used in one cage which covered by screen net for 50 individuals seedlings (2-4 true leaves). In this study, an inoculum strain collected from Kersana-Brebes was used. Genotype IPBC-12 was used as a control resistant genotype. The number of screened seedlings for each genotype was 200 individuals without replication.

Some parameters were observed from M₁ and M₂ population. In M₁ population, parameters observed were seeds germination, seedling height, percentage of abnormal seedlings, chimera and male sterility phenomena, LD₅₀ point, plant height at flowering stage, fruit length, fruit diameter, weight per one fruit, and fruit numbers per plant. Meanwhile, parameters observed in M₂ population were the coefficient variance genetic (CVG), heritability (h²bs), disease symptoms (scoring) and incubation time as resistance parameter to Begomovirus and also some other agronomical traits. Scoring of disease symptoms was shown Figure 1. All data were initially analyzed by using F test and any significant result was further tested by using the DMRT (Duncan Multiple Range Test) at 5% significance level.

![Figure 1. Scoring of disease symptom: 0 = no symptom (healthy); 1 = mild mosaic; 2 = mosaic, yellowing contrast; 3 = mosaic, yellowing contrast, leaf malformation; 4 = acute mosaic, yellowing contrast, leaf malformation](image-url)
RESULTS AND DISCUSSION

Seeds Germination Percentage and Seedling Height

Results showed that there were significant interactions between the five chilli genotypes and gamma rays irradiation dosages for seed germination percentage ($F_{\text{count}} = 35.99^{**} > F_{\text{tab01}} = 2.49$) and seedling height ($F_{\text{count}} = 11.08^{**} > F_{\text{tab01}} = 2.49$). The highest percentage of seed germination was showed by control dose (0 Gy) on five chilli genotypes (85.67-89.33%), while the combination of genotype SSP and 200 Gy dosages (85.00%) showed the highest germination percentage among the irradiated genotypes (Table 1). Reduction in seed germination percentage might have been due to the effect of gamma rays irradiation on meristematic tissues of the seed (Sheppard et al., 1986). Moreover, Dhakshanamoorthy et al. (2010) indicated that the decrease in seed germination at higher dosage of mutagens may be attributed to disturbances at cellular level caused either at physiological or physical level. Ussuf and Nair (1974) said that gamma rays irradiation interfered with the synthesis of enzymes and at the same time accelerated the degradation of existing enzymes involved in the formation of auxins, and thus reduced the seed germination.

Table 2 showed that the treatment of Genotype Lembang-1 irradiated by 200 Gy dosage had the highest seedling height (12.00 cm) even compared to control (0 Gy). This indicated that 200 Gy dosage of gamma rays treatment had a stimulatory effect on the growth of seedling. This result was in line with the study of Dhakshanamoorthy et al. (2010) which suggested that the stimulatory effect on the seedling height was usually observed at a lower dosage of gamma rays. Hypothetically, the origin of these stimulations by irradiation was due to cell division rates, as well as an activation of growth hormone, e.g. auxin (Zaka et al., 2004). Results also showed that the dosage of 800 Gy would drastically reduce chilli seedling height in all genotypes. This indicated that 800 Gy was considered as the dosage of gamma rays irradiation that was too extremely high for chilli seed.

Seedlings physiological damaged that caused by gamma rays irradiation usually correlated with mutation frequency. Irradiation could have direct effect on chromosomes. They might directly break chromosomes or alter one of the DNA bases or indirectly might initiate a chain of physical and chemical reactions. The biological effect also depended on the type of cell and stage of nuclear cycle. For instance, chromosomes were extremely sensitive to breakage in mitotic prophase. The frequency of mutants per viable organism often increased linearly with the dosage (Dhanavel et al., 2012).

Determining of LD$_{50}$ Point

The success of gamma rays irradiation was determined by the genotype radio sensitivity. They could be measured by lethal dose 50 (LD$_{50}$) point. Usually, the parameter used for determining LD$_{50}$ point is the percentage of seed germination. LD$_{50}$ point is lethal dosage for 50% of seed germination. Within the range of LD$_{50}$ point the existence of maximum cell mutant number can be predicted (Dwiatmini et al., 2009). LD$_{50}$ point was determined by using Finney method that was standardized to control (0 Gy).

Table 1. Seed germination of five irradiated chilli genotypes by several dosage levels of gamma rays at 30 days after sowing (DAS)

| Genotypes | 0     | 200   | 400   | 600   | 800   |
|-----------|-------|-------|-------|-------|-------|
| Kencana   | 88.67 aA | 79.67 bB | 55.33 cC | 41.00 dB | 4.00 eAB |
| Lembang-1 | 85.67 aB | 80.33 bB | 55.00 cC | 15.17 dC | 3.33 eAB |
| SSP       | 88.67 aA | 85.00 bA | 75.50 cA | 48.00 dA | 5.00 eA  |
| Tanjung-2 | 88.33 aA | 76.67 bC | 51.00 cD | 14.00 dC | 2.33 eB  |
| Seloka    | 89.33 aA | 79.33 bB | 68.33 cB | 50.17 dA | 5.00 eA  |

Remarks: Numbers followed by different lowercase in a row and uppercase letters in a column indicated significant differences at 0.05 level according to DMRT
Table 2. Seedling height of five irradiated chilli genotypes by several dosage levels of gamma rays at 30 days after sowing (DAS)

| Genotypes | Gamma rays doses (Gy) | 0    | 200  | 400  | 600  | 800  |
|-----------|-----------------------|------|------|------|------|------|
| Kencana   |                       | 10.50 aB | 10.33 aC | 8.33 bD | 3.17 cB | 1.00 dA |
| Lembang-1 |                       | 9.83 BC | 12.00 aA | 9.00 bBC | 2.67 cB | 1.17 dA |
| SSP       |                       | 10.33 aB | 9.17 bD | 9.00 bBC | 5.17 cA | 1.00 dA |
| Tanjung-2 |                       | 11.50 aA | 11.17 aB | 8.83 bCD | 2.50 cB | 1.00 dA |
| Seloka    |                       | 11.17 aA | 10.83 aBC | 10.50 bA | 5.83 cA | 1.17 dA |

Remarks: Numbers followed by different lowercase letters in a row and uppercase letters in a column indicated significant differences at 0.05 level according to DMRT

Table 3. Lethal doses 50 (LD<sub>50</sub>) point of five irradiated chilli genotypes by gamma rays

| Genotype     | Curve formula | LD<sub>50</sub> (Gy) |
|--------------|---------------|----------------------|
| Kencana M<sub>1</sub> | Y=100.108-0.043x+9.2625e005x<sup>2</sup> | 538.41 |
| Lembang-1 M<sub>1</sub> | Y=99.38+0.11x-0.00076x<sup>2</sup>+5.8364e-007x<sup>3</sup> | 448.84 |
| SSP M<sub>1</sub> | Y=98.67+0.04x-0.0002x<sup>2</sup> | 614.79 |
| Tanjung-2 M<sub>1</sub> | Y=99.45+0.045x-0.0006x<sup>2</sup>+4.64e007x<sup>3</sup> | 422.64 |
| Seloka M<sub>1</sub> | Y=100.22-0.091x+0.00021x<sup>2</sup>-3.0318e.007x<sup>3</sup> | 629.68 |
| Average     |               | 530.87               |

The analysis showed that LD<sub>50</sub> point of five irradiated chilli genotypes ranges between 422.64 Gy and 629.68 Gy with Genotype Tanjung-2 was the lowest and Seloka was the highest (Table 3). The average LD<sub>50</sub> point (530.87 Gy) was different from previous study conducted by Omar et al. (2008) that indicated the LD<sub>50</sub> point for chilly was 445 Gy. This might be explained by the fact that radio sensitivity among chilli genotypes was varied and each chilli genotype had specific LD<sub>50</sub> point. Therefore, it was necessary to determine LD<sub>50</sub> point for assessing an optimum dosage for each chilli genotype and obtaining the positive mutant.

Effect of Irradiation on Physiological Abnormality

The results showed that at 600 Gy dosages, there were three M<sub>1</sub> plants of Genotype Kencana (0.50%) were failed to produce fruits. There was a possibility that the three plants were male sterile plants. In general, the shape of sterile pollen was clear and wrinkle because it did not contain amylum. The amount and diameter of sterile pollen were lower than that of fertile one. Moreover, the existence of male sterility phenomenon could be used for improving hybrid variety cytoplasmic male sterile (CMS). In M<sub>1</sub> population with 600 Gy, there were also five plants of Genotype Kencana (0.83%) and two plants of Genotype Tanjung (0.33%) that showed chimera leaf phenomenon. This phenomenon indicated that there was a competition between mutant and normal leaf cells inside the plants. At the growing stage, if normal cells were more dominant than mutant cells, the developing young leaves would be normal again. On the contrary, if mutant cells were more dominant, the chimera phenomena would be going to their progenies. Seedlings condition at 800 Gy dosages had seed germination lower than 20% and a lot of abnormal seedlings, therefore all the irradiated seeds could not be planted in the field.

Plant breeders suggested that the use of irradiation dosage should not be higher than LD<sub>50</sub> point because the mutagens will cause bad physiological effects, such as low seed germination percentage, male sterility, chimera phenomenon, seedling abnormality, dwarf, late flowering, etc. On the other hand, if the dosage was lower than LD<sub>50</sub> point, there was a possibility for being unable the obtain mutants (Soeranto et al., 2001). In general, high gamma rays dosages, particularly 600 and 800 Gy had negative effects physiologically on chilli seedlings derived from irradiated seeds. This indicated that gamma rays irradiation had been used higher than the recommended dosage for chilli seed.
Table 4. Several agronomical traits of five irradiated chilli M₁ genotype affected by some gamma rays dosages

| Treatments       | Plant height at flowering stage (cm) | Fruit length (cm) | Fruit diameter (mm) | Weight per fruit (g) | Fruit number per plant (number) |
|------------------|-------------------------------------|-------------------|---------------------|----------------------|-------------------------------|
| **Main plot:**   |                                     |                   |                     |                      |                               |
| Kencana          | 20.42 b                             | 11.18 b           | 7.79 c              | 2.75 c               | 165.33 a                      |
| Lembang-1        | 26.17 a                             | 9.06 c            | 7.15 c              | 2.34 c               | 108.67 b                      |
| SSP              | 20.17 bc                            | 13.92 a           | 11.05 b             | 5.54 b               | 97.00 b                       |
| Tanjung-2        | 19.00 bc                            | 10.05 c           | 15.14 a             | 6.28 b               | 24.00 d                       |
| Seloka           | 16.42 d                             | 13.29 a           | 15.86 a             | 7.58 a               | 65.58 c                       |
| **Sub plot:**    |                                     |                   |                     |                      |                               |
| 0                | 23.53 a                             | 12.20 a           | 11.86 a             | 5.38 a               | 110.13 a                      |
| 200              | 21.87 b                             | 11.74 ab          | 11.39 b             | 5.04 b               | 98.67 b                       |
| 400              | 19.53 c                             | 11.38 b           | 11.16 b             | 4.63 c               | 88.00 c                       |
| 600              | 16.80 d                             | 10.69 b           | 11.19 b             | 4.54 c               | 71.67 d                       |
| **ANOVA**        |                                     |                   |                     |                      |                               |
| Genotype (G)     | **                                  | **                | **                  | **                   | **                            |
| Irradiation doses (D) | **                                  | ns                | **                  | ns                   | ns                            |
| G x D            | ns                                  | ns                | ns                  | ns                   |                               |

Remarks: Mean followed by the same letter are not significantly at 0.05 level according to DMRT; ** = highly significant; ns = non-significant

Effect of Gamma Rays Irradiation to Several Agronomical traits on M₁ Plant Population

Results of variance analysis (Table 4) showed that there was no interaction between irradiated chilli genotypes and gamma rays irradiation dosages for some parameters, such as plant height at flowering, fruit length, fruit diameter, weight per fruit, and fruit number per plant. Genotype M₁ Seloka showed the longest fruit length (13.29 cm), longest fruit diameter (15.86 mm), and higher weight per fruit (7.58 g) as compared to the other four genotypes. Genotype M₁ Lembang-1 had the highest plant height (26.17 cm) while Genotype M₁ Kencana had the highest fruit number per plant (165.33 fruits). In general, increasing gamma rays irradiation dosage might have a consequence of increasing negative effects. All parameters were recorded maximum at the control treatment (0 Gy), and recorded minimum at 600 Gy dosage. Previous study suggested that lower dosage could become a stimulatory effect to some agronomical traits (Dhakshanamoorthy et al., 2010), however in this study, both lower and higher dosage of gamma rays treatments had shown an inhibitory effect as compared to control.

Genetic Variance of Some Characters of M₂ Plant Population

Table 5 showed that in M₂ plant population, both the coefficient of variance genetic (CVG) and broad sense heritability (h²bs) of disease symptom scoring parameter for Begomovirus were low. However, the disease incubation parameter was rather high. This indicated an escalation of resistance to Begomovirus for each individual in M₂ as the incubation time varied (Figure 2). Genotype M₂ Kencana performed the best in terms of disease incident (29.17%) and disease intensity percentage (10.00%). But, out of the five irradiated chilli genotypes, IPBC-12 as a resistant genotype control, showed a high resistance level. It was indicated by the low disease incident percentage that was only 21.35% and disease intensity that was 8.33%. Unfortunately, the fruit performance of Genotype IPBC-12 could not satisfy the criteria of an ideal chilli fruit idiotype. Nevertheless, this genotype could still be collected as germplasm for the source of Begomovirus resistant gene.
### Table 5. Coefficient of variance genetic (CVG) and broad sense heritability ($h^2_{bs}$) on $M_2$ plant population

| Traits                        | $M_2$ Kencana | $M_2$ Lembang1 | $M_2$ SSP | $M_2$ Tanjung 2 | $M_2$ Seloka |
|-------------------------------|---------------|----------------|-----------|----------------|-------------|
| **Symptom Scoring (0-4)**     |               |                |           |                |             |
| Mean                          | 1.39          | 2.47           | 1.83      | 2.06           | 2.06        |
| $\sigma^2_g$                  | (-1.07)       | 0.15           | (-0.70)   | (-0.08)        | (-0.46)     |
| $h^2_{bs}$                    | (-2.06)       | 0.08           | (-0.63)   | (-0.05)        | (-0.30)     |
| CVG                           | (-74.42)      | 15.68          | (-45.72)  | (-13.73)       | (-32.92)    |
| Criteria                      | Low           | Rather low     | Low       | Low            | Low         |
| **Incubation time (DAI)**     |               |                |           |                |             |
| Mean                          | 16.32         | 14.95          | 16.19     | 15.77          | 15.86       |
| $\sigma^2_g$                  | 13.56         | 12.25          | 12.91     | 13.89          | 13.20       |
| $h^2_{bs}$                    | 0.77          | 0.42           | 0.72      | 0.81           | 0.71        |
| CVG                           | 22.56         | 23.41          | 22.2      | 23.64          | 22.91       |
| Criteria                      | Rather high   | Rather high    | Rather high| Rather high    | Rather high |
| **Plant Height (cm)**         |               |                |           |                |             |
| Mean                          | 72.17         | 53.29          | 59.75     | 37.92          | 24.59       |
| $\sigma^2_g$                  | 604.59        | 355.09         | 215.83    | 89.28          | 165.8       |
| $h^2_{bs}$                    | 0.97          | 0.95           | 0.91      | 0.92           | 0.94        |
| CVG                           | 34.07         | 35.36          | 24.59     | 24.92          | 23.37       |
| Criteria                      | High          | High           | Rather high| Rather high    | Rather high |
| **Fruit Number (fruits)**     |               |                |           |                |             |
| Mean                          | 180.05        | 119.36         | 120.45    | 49.57          | 87.67       |
| $\sigma^2_g$                  | 809.28        | 683.64         | 232.44    | 268.81         | 369.88      |
| $h^2_{bs}$                    | 0.87          | 0.91           | 0.8       | 0.98           | 0.88        |
| CVG                           | 15.8          | 21.91          | 12.66     | 33.08          | 21.94       |
| Criteria                      | Rather low    | Rather high    | Rather low| High           | Rather high |
| **Fruit Length(cm)**          |               |                |           |                |             |
| Mean                          | 12.84         | 10.49          | 14.02     | 11.17          | 13.60       |
| $\sigma^2_g$                  | 8.14          | 1.37           | 1.43      | 1.50           | 2.64        |
| $h^2_{bs}$                    | 0.85          | 0.59           | 0.62      | 0.59           | 0.70        |
| CVG                           | 22.23         | 11.16          | 8.53      | 10.96          | 11.94       |
| Criteria                      | Rather high   | Rather low     | Low       | Rather low     | Rather low  |
| **Fruit Diameter (mm)**       |               |                |           |                |             |
| Mean                          | 7.44          | 7.45           | 11.44     | 15.20          | 15.83       |
| $\sigma^2_g$                  | 0.18          | 0.14           | 2.46      | 0.45           | 12.30       |
| $h^2_{bs}$                    | 0.46          | 0.38           | 0.34      | 0.39           | 0.94        |
| CVG                           | 5.70          | 5.02           | 13.71     | 4.41           | 22.16       |
| Criteria                      | Low           | Low            | Rather low| Low            | Rather high |
| **Weight of One Fruit (g)**   |               |                |           |                |             |
| Mean                          | 3.02          | 2.57           | 6.86      | 7.73           | 7.86        |
| $\sigma^2_g$                  | 0.56          | 0.04           | 2.43      | 3.55           | 3.48        |
| $h^2_{bs}$                    | 0.95          | 0.33           | 0.84      | 0.92           | 0.95        |
| CVG                           | 24.75         | 7.77           | 22.71     | 24.36          | 23.73       |
| Criteria                      | Rather high   | Low            | Rather high| Rather high    | Rather high |

Remarks: Criteria of CVG: 0<x≤10.94 = low; 10.94<x≤21.88 = rather low; 21.88<x≤32.83 = rather high; 32.83<x≤43.77 = high; 43.77<x = very high. Criteria of $h^2_{bs}$: $h^2_{bs}$<0.20 = low; 0.20 $h^2_{bs}$ ≤ 0.50 = moderate; $h^2_{bs}$ > 0.50 = high.
Mutations were phenotypically classified into two groups: macro and micro mutations. Macro mutation was easily detectable in individual plants, phenotypically visible, morphologically distinct, qualitatively inherited genetic changes, and it occurred in major genes or oligogenes. Meanwhile, micro mutation resulted in a small effect that usually could only be detected by the help of statistical methods, quantitatively inherited genetic changes and it occurred in minor genes or polygenes (Dhanavel et al., 2012). Quantitative traits of $M_2$ plant population derived from irradiated seed by gamma rays could be seen in the Table 5 also. Results in Table 5 showed that the CVG and $h^2_{bs}$ for plant height of the five irradiated chilli genotypes were rather high to high. Chilli genotypes of $M_2$ Lembang-1, $M_2$ Tanjung-2, and $M_2$ Seloka had rather high to high CVG and $h^2_{bs}$ value for fruit number. Only Genotype $M_2$ Kencana and $M_2$ Selokahad rather high CVG and $h^2_{bs}$ value for fruit length and fruit diameter, respectively. Except Genotype $M_2$ Lembang-1, the other genotypes had rather high CVG and $h^2_{bs}$ value for weight per fruit. This proved that gamma rays irradiation could also increase chilli genetic variability in morpho-agronomical traits.

**CONCLUSION AND SUGGESTION**

Increasing dosage of gamma rays irradiation caused alternation in physiological and agronomical traits of $M_1$ plant population. LD$_{50}$ points of Genotype Kencana, Lembang-1, SSP, Tanjung-2, Seloka were 538.41 Gy, 448.84 Gy, 614.79 Gy, 422.64 Gy, and 629.68 Gy respectively.

There were some chilli genotypes in the population of $M_2$ that had high coefficient variance genetic (CVG) and broad sense heritability ($h^2_{bs}$) value for disease incubation time. This could be used as resistance parameter to *Begomovirus* and improvement parameter of several agronomical traits.

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