INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
23–0210/2023/30–3–169–176
DOI: 10.17957/IJAB/15.2072
http://www.fspublishers.org

Full Length Article

Performance, Genetic Variability and Heritability of M_1 Generation Mandarin Citrus (*Citrus reticulata*) Mutants

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Received 07 June 2023; Accepted 22 July 2023; Published 28 August 2023

Abstract

Mandarin citrus (*Citrus reticulata* L.) is one of the most popular fruits in Indonesia. Consumers like citrus fruits that have few or no seeds (seedless), easy to peel and have an attractive color. This type of citrus fruit can be obtained through mutation plant breeding followed by selection. This study aimed to examine the performance, determine the genetic variability and predict the heritability of M1 generation local Indonesian mandarin citrus mutants. Irradiation is carried out at the National Nuclear Energy Agency of Indonesia. Materials irradiated were buds from mandarin citrus cultivars, namely Siam Madu, Sitaya and Tawangmangu. Irradiation doses used were 0, 50 and 60 Gy. Buds were irradiated in a Panoramic Gamma (γ) Irradiator with a γ radiation source: Co-60. The results showed that the performance of the mandarin citrus mutant was varied and influenced by genotype and irradiation dose used. Irradiation of 50 Gy could increase shoot length and photosynthesis on Siam madu variety. In the Sitaya variety, the irradiation dose of 60 Gy increased the shoot length. In the Tawangmangu variety, the irradiation dose of 50 Gy increased the shoot length. Genetic variability was obtained on bud color, leaf area, leaf color and net photosynthesis traits. Except for bud length, all observed characteristics showed high broad sense heritability values. Based on wide genetic variability and heightened general sense heritability values, selection for bud color, leaf area, leaf color, and net photosynthesis traits can be performed at early generations using a phenotypical selection method.

Keywords: Mandarin citrus; Mutations; Genetic variability; Broad sense heritability

Introduction

Citrus is a widely consumed fruit and there are many local cultivars in Indonesia. National citrus production in 2021 is 2.51 million tons, a decrease of 7.67% from 2020. Meanwhile, in the same year, citrus household consumption reached 1.15 million tons in 2021, which increased by 29.95% from 2020 consumption (BPS 2022b). Citrus production in 2021 will be mostly contributed by mandarin oranges (*Citrus reticulata* L.). In 2021 mandarin citrus will contribute 2.41 million tons of total national production (BPS 2022a).

Indonesia has several popular local Mandarin citruses, including Siam Madu, Sitaya and Tawangmangu cultivars. One of the local mandarin citrus weaknesses is having a lot of seeds, so consumers do not like them. Criteria for citrus fruits favored by consumers and the global market are having few or no seeds (seedless), being easy to peel and having an attractive color (Karyanti *et al*. 2015). Thus improving the properties of oranges aims to produce quality citrus fruits (in terms of size, sugar and acidity balance, juice yield and seedless) which are healthy and rich in antioxidant compounds, tolerant or resistant to different abiotic and biotic threats, as well as high productivity (Salonia *et al*. 2020).

Improving seedless citrus can be done through plant breeding programs. Conventional citrus breeding is slow and difficult due to its complex reproductive biology, such as slow fruit growth and ripening, heterozygosity, apomixis, polyembryony, parthenocarpy, incompatibility and long juvenile phase (Febres *et al*. 2011; Agisimanto *et al*. 2016; Kim *et al*. 2020; Ollitrault *et al*. 2021). Another alternative method that can be used to solve this problem is plant mutation. Mutations are changes in gene composition, which are reported to improve plant characteristics (Herwibawa *et al*. 2014).

Mutational breeding has shown enormous potential in citrus crop for improvement, especially in economically important horticultural traits (Mustafa *et al*. 2021). Mutation induction has been widely used in citrus to develop varieties with better quality and resistance or tolerance to biotic and abiotic stresses (Kamatyanatt *et al*. 2021). In industrial fruit,

To cite this paper: Farid N, A Riyanto, TS Wahyudiningsih, M Rahmiyah, M Habibullah, Z Ulinnuha (2023). Performance, genetic variability and heritability of M_1 generation mandarin citrus (*Citrus reticulata*) mutants. *Intl J Agric Biol* 30:169–176

mutations are mostly carried out by radiation (physical) or chemical. Most of these mutants are propagated vegetatively. Several sweet orange cultivars resulting from mutations have been widely cultivated. In China, mutations are often carried out in an effort to improve Citrus spp varieties, the resulting new varieties are then cultivated commercially (Kamatyanatt *et al*. 2021).

Mutation induction techniques such as radiation or chemical mutagens are good tools to increase variability within plant species because spontaneous mutations occur with a very low frequency (Sutarto *et al*. 2009). Gamma (γ) rays are widely used as mutagen irradiation in plant mutation breeding (Purba *et al*. 2021; Habibullah *et al*. 2022). Mutation induction with γ rays has been proven effective in several citrus species (Eun and Kim 2022). Irradiation of woody plants with γ rays can produce a higher frequency of mutations, which leads to the creation of new variants compared to the parent varieties (Rattanpal *et al*. 2019).

Mutants can be selected based on morphological, physiological, and molecular markers. One physiological characteristic that determines plant productivity is the rate of photosynthesis. According to (Tang *et al*. 2023), biomass synthesized through photosynthesis affects plant productivity. Increasing the ability of photosynthesis is essential in increasing plant productivity (Faralli and Lawson 2020). In addition, the greenness of the leaves indicates the chlorophyll content, a pigment that plays a role in the light-harvesting complex in higher plants and in absorbing light and transmitting energy. This parameter has yet to be widely used to select mutants, especially the orange mutant.

The γ-ray irradiation effectively increases citrus diversity (Arisah and Mariana 2018; Eun and Kim 2022). The γ-ray irradiation can produce high mutations to create new genetic variability different from the wild-type oranges (Rattanpal *et al*. 2019). Mutation breeding has proven to be a powerful tool for increasing the spectrum of genetic variability (Akhtar *et al*. 2015; Patil and Lokesha 2018). Genetic variability is a prerequisite for initiating crop improvement programs and applying appropriate selection techniques (Chowdhury *et al*. 2023). Studying genetic variability concerning genetic parameters such as genetic variability coefficient and heritability reveals the inheritance of quantitative and qualitative parameters of fruit to design citrus plant breeding strategies (Singh *et al*. 2022).

The genetic variability coefficient is a value that describes the genetic variability of a trait in a population. The genetic variability coefficient gives a better picture of genetic variability (Sudeepthi *et al*. 2020). The genetic variability coefficient can be divided into two, namely, the phenotypic variability coefficient (PCV) and the genotypic variability coefficient (GCV) (Singh *et al*. 2011; Riyanto *et al*. 2021). PCV and GCV are useful in detecting the level of variabilities of a particular trait (Chavan *et al*. 2020).

Heritability shows that a trait is more controlled by genetic factors or environmental factors so that it can be seen to what extent the trait is inherited by to next offspring (Kartahadimaja *et al*. 2021). Heritability is the proportion of genetic variance to phenotypic variance (Khomphet *et al*. 2022). The heritability of a trait is very important in determining the response to selection (Riyanto *et al*. 2021), and this illustrates the effectiveness of genotypic selection based on phenotypic performance (Shah *et al*. 2018).

Mutation induction can increase the genetic diversity of Siam Madu, Sitaya and Tawangmangu mandarin citrus cultivars. In this mandarin citrus mutant population, genetic variability and heritability information is required to make selection efficient. This study aimed to examine the performance, determine the genetic variability, and predict the heritability of M1 generation local Indonesian mandarin citrus mutans.

Materials and Methods

Experimental location

Gamma irradiation treatment was carried out at the Center for Application of Isotope and Radiation Technology, National Nuclear Energy Agency. The experiment was carried out in citrus land in Kembanglimus Village, Borobudur District, Magelang Regency. The research was conducted from March to September 2022.

Experimental materials

The buds were treated with γ-irradiation, with insert the buds into the Gamma Chamber ^{60}Co (the irradiation rate is 510 Gy. h^{-1}). Citrus plants grafted with citrus buds that have been irradiated at doses of 0, 50 and 60 Gy were used in this study. The irradiated buds were mandarin citrus cultivar *i.e*., Siam Madu, Sitaya and Tawangmangu. Radiated scion shoots were taken from one-year-old branches approximately 0.6 cm in diameter. The selected scion shoots have round and sturdy criteria so that when taken, the buds are not damaged.

Experimental design

The experimental design was a factorial randomized block design with three replications. There are two factors tested, namely γ-ray irradiation dose and citrus genotype. The γ irradiation doses tested were 0, 50 and 60 Gy. Citrus genotype consisted of Siam Madu, Sitaya and Tawangmangu cultivars. Mandarin citrus buds cv. Siam Madu, Sitaya and Tawangmangu with criteria bud length 20–25 cm, there are 3–8 buds, taken from branches that are protected from pests and diseases, buds are selected from plants whose cambium is active which is indicated by the presence of new shoots. Buds were irradiated using γ rays with doses of 0, 50 and 60 Gy in the γ chamber.

Bud grafting

The irradiated buds were grafted onto a five-year-old mandarin citrus tree by means of bud grafting. The first step in the budding stage is slicing the rootstock. The irradiated buds are then inserted into the grafting slices on the rootstock. Then do the binding on the bud grafting.

Data collection

Data were collected on the buds at 12 weeks after grafting. Variables observed were bud length, bud color, leaf area, leaf color using leaf color chart. The photosynthetically active radiation (PAR), net photosynthesis, stomatal conductance, and respiration measured with the CI-340 Handheld Photosynthesis. To measure photosynthetic and other activities, placed a leaf in the CI-340 sensor to measure leaf gas exchange under ambient conditions or in a closed system.

Statistical analysis

To determine the performance of observed traits data obtained were analyzed for variance at an error level of α 5% (Table 1). If there is a significancy, continue with Duncan's Multiple Range Test at an error level of 5%. Estimate of genetic parameters was calculated followings.

Estimation of phenotypic variance (σ_p^2) genotypic variance (σ_g^2), and environmental variance (σ_e^2)

The phenotypic variance, genotypic variance and environmental variance were estimated based on the estimation of the mean square of analysis of variance (Table 1), calculated in the following (Annicchiarico 2002; Jambormias 2014).

$$\sigma_e^2 = M1$$

$$\sigma_{dg}^2 = \frac{M2 - M1}{r}$$

$$\sigma_g^2 = \frac{M3 - M1}{rd}$$

$$\sigma_p^2 = \sigma_g^2 + \frac{\sigma_{dg}^2}{d} + \frac{\sigma_e^2}{rd}$$

Where, σ_e^2 = environmental variance, σ_{dg}^2 = interaction of radiation dose x genotype variance, σ_g^2 = genotypic variance dan σ_p^2 = phenotypic variance.

Estimation of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV)

Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were calculated following (Singh and Chaudhary 1979).

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\sqrt{\sigma_p^2}}{\bar{X}}$$

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sqrt{\sigma_g^2}}{\bar{X}}$$

Where, σ_p^2 = phenotypic variance, σ_g^2 = genotypic variance and $\bar{X}$= population mean value.

PCV and GCV are grouped into high (coefficient value more than 20%), moderate (coefficient value between 10–20%) and low (coefficient value less than 10%) (Sivasubramanian and Menon 1973).

Estimation of broad sense heritability (h^2_{bs})

Broad meaning heritability (h^2_{bs}) were calculated following (Roy 2000).

$$Broad\ sense\ heritability\ (h_{bs}^2) = \frac{\sigma_g^2}{\sigma_p^2} x100\%$$

Where, σ_p^2 = phenotypic variance, σ_g^2 = genotypic variance and $\bar{X}$= population mean value.

Broad sense heritability is categorized into high (value greater than 50%), moderate (between 50 and 20%) and low (value less than 20%) (Stansfield 1991).

Results

Performance of mandarin citrus mutants at several γ ray irradiation doses

Two weeks after the bud grafting, the success of the bud grafting started to be seen, as indicated by the fresh buds. The analysis showed that radiation dose caused significant differences in bud length, color, leaf color and net photosynthesis. Genotype led to marked differences in all observed traits. The interaction between radiation dose and genotype significantly differed in bud length, color, leaf color and net photosynthesis.

Table 3 shown that Irradiation of 50 Gy in Siam Madu increased the bud length but was not significantly different by 64.37 cm compared to the control, which was 51.20 cm, and in Tawangmangu, it increased by 35.27 cm compared to the control, which was 21.21 cm. An irradiation dose of 60 Gy increased the bud length in Sitaya by 46.51 cm compared to the control, which was 25.98 cm. But in Siam madu, the dose of 60 Gy reduced the bud length to 16.49 cm; in Tawangmangu, it decreased to 16.97 cm.

At an irradiation dose of 50 Gy, Siam Madu increased leaf color by 3.25 compared to the control, which was 2.17 cm; net photosynthesis increased by 12.07 cm compared to the control, which was 6.67 cm. In Sitaya and Tawangmangu, there were no significant changes in the 50 and 60 Gy irradiation treatments.

Genetic variability and broad sense heritability of M_1 generation Mandarin citrus mutants

Analysis of variance showed that there was variation in the

Table 1: Model of analysis of irradiation dose, genotype and interaction of irradiation dose x genotype of M_1 generation mandarin citrus mutant traits

Source of variation	Df	Sum square	Mean Square	Variance component
Block	r-1	SSr	M5	
Irradiation dose (D)	d-1	SSd	M4	$\sigma_e^2 + r\sigma_{dg}^2 + rg\sigma_d^2$
Genotype (G)	g-1	SSg	M3	$\sigma_e^2 + r\sigma_{dg}^2 + rd\sigma_g^2$
D x G interaction	(d-1) (g-1)	SSdg	M2	$\sigma_e^2 + r\sigma_{dg}^2$
Error	(r-1) (ab-1)	SSe	M1	σ_e^2
Total	rdg-1			

Table 2: Means square of analysis of ANOVA of M_1 generation mandarin citrus mutant traits

Traits	Irradiation dose (D)		Genotype (G)		D x G Interaction	
Bud length	1071.68	*	1159.48	*	1081.76	*
Bud color	3.06	*	7.91	*	1.52	*
Leaf area	81.04		280.22	*	60.95	
Leaf color	1.97	*	12.71	*	1.18	*
PAR	131434.45		707802.65	*	139516.97	
Net photosynthesis	17.59	*	144.19	*	10.42	*
Respiration	0.06		2.10	*	0.86	
Stomatal conductance	1855.26		2352.90	*	376.90	

Remark: * = significantly different at α = 5%.

Table 3: Interaction effect of irradiation dose and genotype of M_1 generation mandarin citrus mutant traits

Genotype	Irradiation dose (Gy)	Bud length (cm)		Bud color		Leaf color		Net photosynthesis	
Siam Madu	0	51.20	a	3.15	a	2.17	b	6.67	b
	50	64.37	a	3.32	a	3.25	a	12.07	a
	60	16.49	b	1.21	b	1.22	b	6.87	b
Sitaya	0	25.98	b	4.42	a	3.79	a	9.44	a
	50	35.99	ab	3.78	a	3.92	a	10.35	a
	60	46.51	a	3.83	a	3.65	a	9.74	a
Tawangmagu	0	21.21	ab	4.05	a	4.33	a	14.85	a
	50	35.27	a	4.00	a	4.12	a	15.22	a
	60	16.97	b	3.73	a	4.00	a	15.19	a

Remark: * numbers followed by the same letter for the same factor and traits were not significantly different in the DMRT at α = 5%

Table 4: Phenotypic variance, genotypic variance, environmental variance, phenotypic coefficient of variation, genotypic coefficient of variation and broad sense heritability of M_1 generation mandarin citrus mutant traits

Traits	σ^2_p	σ^2_g	σ^2_e	PCV (%)	GCV (%)	h^2_{bs} (%)
Bud length	122,75	6,48	141,35	31,76	7,29	5,28
Bud color	0,69	0,53	0,27	23,82	20,86	76,71
Leaf area	3,15	2,84	1,53	72,12	68,51	90,25
Leaf color	1,08	0,96	0,40	30,73	28,98	88,94
PAR	12,25	11,15	1,99	31,37	29,93	91,00
Net photosynthesis	61053,35	47357,14	65004,36	15,68	13,81	77,57
Respiration	0,18	0,10	0,59	13,92	10,49	56,81
Stomatal conductance	187,69	164,67	678,89	13,90	13,02	87,74

remark: σ_p^2 = phenotypic variance, σ_g^2 = genotypic variance, σ_e^2 = environmental variance, PCV = phenotypic coefficient of variation, GCV = genotypic coefficient of variation and h^2_{bs} = broad sense heritability.

genotypes factor (Table 2). Table 4. shows the phenotypic variance of all observed variables, which is greater than the genotypic variance. This result was followed by a PCV greater than the GCV. GCV values for the observed properties ranged from 7.29 – 68.51%. Bud color, leaf area, leaf color and net photosynthesis showed KKG values above 20%, respectively 20.86, 68.51, 28.98 and 29.93%.

Broad sense heritability estimation value of observed traits ranged from 5.28–91.00% (Table 4). Traits that show a value above 50% are bud color (76.71%), leaf area (90.25%), leaf color (88.94%), net photosynthesis (91.00%), PAR (77.57%), respiration (56.81%) and stomatal conductance (87.74%).

Discussion

As regards performance of γ-irradiated mandarin mutants, ANOVA shows that bud length, bud color, leaf color, and net photosynthesis were affected by the interaction between irradiation doses and mandarin citrus cultivars (Table 2).

Irradiation dose affected bud color, leaf color and net photosynthesis only in the Siam Madu cultivar but did not affect Sitaya and Tawangmangu cultivars. The bud length at Siam Madu increased at a dose of 50 Gy irradiation, namely 64.37 cm, compared to the control, which was 51.20 cm, but the bud length decreased at an irradiated dose of 60 Gy to 16.49 cm. This was also experienced in the Tawangmanu variety, which experienced an increase in bud length at the 50 Gy dose, namely 35.27 cm, compared to the control, which was only 21.21 cm; at the 60 Gy irradiation dose, decreased to 16.97 cm; In contrast to the Sitaya variety, which experienced an increase in bud length at an irradiation dose of 60 Gy to 46.51 cm, compared to the control, which was 25.98 cm. This shows that the growth in the mutant is faster than in the control. Faster growth indicates an improvement in plant physiology in accumulating photosynthetic biomass Nowicka *et al*. (2018) states that the biomass synthesized through photosynthesis is a factor that determines plant productivity, So the increase in the bud's length indicates that the mutant obtained will produce more optimum productivity than the control. This means that the irradiation dose 50 Gy is effective for the Siam Madu cultivar. These results agree with other studies that the LD50 in the bud was obtained at a dose of 50 Gy γ irradiation (Latado *et al*. 2012; Pérez-Jiménez *et al*. 2020).

There was no significant difference in the bud color of all varieties at 50 Gy irradiation. In the Siam Madu irradiation dose of 60 Gy, the bud color decreased in the score, which was 1.21, compared to the control, which was 3.15. This indicates an abnormality in the formation of color pigments in the bud, which causes stunted development of the bud. In Sitaya and Tawangmangu varieties, both also experienced a decrease in bud color scores, but not significantly different from the control. In the Sitaya variety, the bud color at a dose of 60 Gy is 3.83, compared to the control, which is 4.42, while in the Tawangmangu variety at an amount of 60 Gy, it is 3.73 compared to the control, which is 4.05. The results of this study indicate that the level of irradiation dose and genotype influences the success of γ-ray irradiation. The rate of mutation induction can be determined by critical factors such as γ-ray irradiation dose and genotype used (Sutarto *et al*. 2009; Pérez-Jiménez *et al*. 2020; Yarar *et al*. 2022).

The level of greenness of the leaves on the Siam madu variety at a dose of 50 Gy increased by 3.25 compared to the control, which was 2.17. Meanwhile, Sitaya and Tawangmangu experienced an increase in leaf greenness, but not significantly different from the control. The level of greenness of the leaves shows the quantity of chlorophyll contained in the leaves. *Chlorophyll* is a pigment that plays a role in light harvesting antennas in higher plants. Chlorophyll plays a role in absorbing and transmitting energy. Belgio *et al*. (2012) added that chlorophyll content is a factor that determines the size of a light-harvesting antenna.

At an irradiation dose of 60 Gy, the Siam Madu variety experienced a decrease in leaf greenness compared to the control, which was 1.22, compared to the control, which was 2.17, but not significantly different. Sitaya and Tawangmangu also experienced a decrease in leaf greenness, but this was not significantly different from the control. Damage to the chlorophyll biosynthesis stage will result in the loss of the green color of the leaves (Zhu *et al*. 2017). Disturbance in chlorophyll biosynthesis can damage the redox balance, which causes damage to members resulting in chlorophyll deficiency in mutants. Abnormalities in chloroplast chloroplasts cause a decrease in photosynthetic performance in mutants.

Net photosynthesis in Siam Madu at a dose of 50 Gy irradiation increased, namely 12.07 compared to the control, which was 6.67. Meanwhile, the Sitaya and Tawangmangu varieties experienced an increase but were not significantly different from the control. The net increase in photosynthesis in Sitaya was 9.63% compared to the control, and in Tawangmangu, it was 2.49%. At an irradiation dose of 60 Gy, all varieties tested experienced an increase, but not significantly different. Net photosynthetic enhancement value at 60 Gy irradiation dose on Siam Madu.

There is a positive relationship between the level of leaf greenness and net photosynthesis. The Siam Madu variety experienced an increase in leaf greenness at an irradiation dose of 50 Gy, accompanied by an increase in net photosynthesis. In the Sitaya and Tawangmangu varieties, the γ-ray irradiated mutant did not experience a significant change in the greenness of the leaves. No significant change in net photosynthesis also accompanied this. In previous studies, increased chlorophyll content in tobacco and arabidopsis led to increased photosynthetic activity (Biswal *et al*. 2012). Bassuony and Zsembeli (2021) also reported a significant relationship between chlorophyll content and net photosynthesis in rice inbred lines under sufficient water conditions. But, all varieties irradiated with 60 Gy γ rays did not significantly change the level of the greenness of the leaves; this resulted in net photosynthesis in all varieties that were irradiated and did not experience a significant change. The relationship between leaf greenness and photosynthesis makes this parameter a criterion for selecting mutants that produce high productivity.

There are a variety of different relationships in net photosynthesis with bud length. This bud length indicates the amount of biomass produced from photosynthesis. The Siam Madu variety irradiated at 50 Gy experienced a significant increase in net photosynthesis compared to the control, but the shoot length increased but not significantly. In the Sitaya variety, shoot length was significantly increased at 60 Gy irradiation dose. However, the net photosynthesis at 60 Gy irradiation increased but not significantly compared to the control. The Tawangmangu variety irradiated at 50 Gy increased shoot length, but the resulting net photosynthesis was not significantly different from the control. However, in general, an increase in photosynthesis results in an increase in growth characterized by an increase in shoot length. It was do with optimal carbon balance is essential in the process of photosynthesis. The optimal ratio of source and sink activities aims to photosynthate and then be exported from the source to the sink (Bassuony and Zsembeli 2021). In the results of this study, although the net photosynthetic value was more or less the same in the Sitaya and Tawangmangu varieties, the shoot growth obtained was different. This shows a difference in the balance of source and sink activities so that the same photosynthetic activity can produce different sink values. Idris *et al*. (2018) adds to the complexity of the relationship between chlorophyll biosynthesis, the size of light-harvesting antennas, and the efficiency of light use and carbon sequestration and conversion mechanisms, resulting in differences in the biomass accumulated from photosynthesis.

The results regarding genetic variability and broad sense heritability showed that there was a variance in the observed genotypes. Variance can be separated into phenotypic, genotypic and environmental (Yani *et al*. 2018). So that information about the contribution of genetic variability to the total observed variance can be known.

This study's PCV value was more significant than the GCV value for all observed traits. PCV reflects the influence of environmental factors and GCV describes the influence of genetic factors on a trait (Kishore *et al.* 2015; Chozin *et al*. 2017). PCV, which is greater than GCV, indicates an influence of the environment on the expression of the observed trait (Choudhary *et al*. 2018; Sudeepthi *et al*. 2020). The genetic variability of bud color, leaf area and leaf greenness were included in the high diversity category. In addition, in the analysis of phenotypic diversity, there was an increase in value, but not significantly compared to genetic diversity, especially in bud length. The GCV value of the bud length shows low variability, but the PCV shows high variability. This shows the dominance of environmental influences over genetic influences on bud length.

The slight difference between PCV and GCV indicates that genetic factors are more influential than environmental factors, as shown by bud color, leaf area, net photosynthesis, respiration and stomatal conductance. Selection based on the phenotype for traits that have almost the same GCV and PCV values will be effective for improving these traits. Therefore, the selection of citrus mandarin mutants can be based on bud color, leaf area, net photosynthesis, respiration and stomatal conductance.

A genotypic coefficient of variation, which is above 20%, is categorized as high value and indicates wide genetic variability (Sivasubramanian and Menon 1973). The results of this study showed that the GCV values of bud color, leaf area, leaf color, and net photosynthesis were above 20%, reflecting that these traits have a broad genetic variability. Wide genetic variability in the population provides flexibility in selection to assemble a new variety with traits suitable for the purpose (Bornare *et al*. 2014).

Heritability broad sense value of bud color, leaf area, leaf color, net photosynthesis, PAR, respiration, and stomatal conductance traits above 50%. Heritability values above 50% are categorized as high heritability (Stansfield 1991). This means that bud color, leaf area, leaf color, net photosynthesis PAR, respiration and conductance traits have high heritability values.

Traits with high heritability values indicate that genetic factors are more influential than environmental factors on the performance of these traits (Riyanto *et al*. 2023a). Simple selection methods can improve traits with high heritability values (Raghavendra and Hittalmani 2016). In addition, the selection of traits with high heritability values can be carried out in the early generations because dominant genetic factors influence plant phenotypes (Lestari *et al.* 2015) thus accelerating the cultivar development process (Riyanto *et al*. 2023b). Therefore, based on the heritability value, the selection of buds color, leaf area, leaf color, net photosynthesis, PAR, respiration, and stomatal conductance traits can be made at the beginning of the generation using a simple selection method.

Selecting a trait will be effective if genetic variability and heritability are combined. In this study, based on genetic variability and heritability, selection for bud color, leaf area, leaf color and net photosynthesis traits can be performed at early generations using a simple selection method.

Conclusion

The results showed that the performance of the mandarin citrus mutant was varied and influenced by genotype and irradiation dose used. 50 Gy irradiation can increase shoot length and photosynthesis in Siam madu varieties. In the Sitaya variety, an irradiation dose of 60 Gy increased shoot length. However, the Tawangmangu variety was affected by an irradiation dose of 50 Gy. Genetic variability was obtained on bud color, leaf area, leaf color and net photosynthesis traits. Except for bud length, all observed traits showed high broad sense heritability values. Based on wide genetic variability and high broad sense heritability values, selection for bud color, leaf area, leaf color and net photosynthesis traits at early generation using a simple selection method may be considered.

Acknowledgements

This work was supported by research grants from the Institute for Research and Community Service of Tidar University, Magelang, Indonesia.

Author Contributions

All authors participated in the elaboration, discussion and writing of this paper and they are responsible for the content of the manuscript.

Conflicts of Interest

All authors declare no conflict of interest.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable to this paper.

Funding Source

Institute for Research and Community Service of Tidar University, Magelang, Indonesia

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