EFFECT OF GAMMA IRRADIATION ON SEED GERMINATION, STORAGE, AND SEEDLING GROWTH OF *Magnolia champaca* L.

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EFFECT OF GAMMA IRRADIATION ON SEED GERMINATION, STORAGE AND SEEDLING GROWTH OF *Magnolia champaca* L. Gamma irradiation of seeds is known as an important factor in stimulating biochemical and physiological processes. This paper investigates the effect of seed irradiation on the seed germination, storability, and seedling growth traits of *Magnolia champaca*. Seeds were irradiated with 0, 5, 10, 15, 20, 40, 60, 80 and 100 Gy by Cobalt-60. The treated seeds were grouped into three lots, namely germination test, storage test and seedling growth characteristics. Observations were made for seed germination percentage, germination index, mean germination time, germination value and growth traits such as height, collar diameter, number of leaves, root length, and dry weight. Results showed that irradiation at a dose of 30 Gy was close to LD50, and irradiation at doses of 80 Gy and higher caused lethal effect. The maximum increase of germination parameters on irradiated seed was recorded at a dose of 10 Gy, and then it decreased. Growth rate in terms of seedling height, collar diameter, number of leaves, and dry weight have also increased in gamma irradiation doses up to 80 Gy, but the dose of 10 Gy resulted in survival and growth that was more stable and gave the highest values for most of the parameters. Hence, lower dose (10 Gy) of irradiation treatment can be used to increase seed germination, storability and seedling growth of *M. champaca*.

Keywords: *Magnolia champaca,* gamma irradiation, germination, growth

PENGARUH IRADIASI SINAR GAMMA TERHADAP PERKECAMBAHAN, PENYIMPANAN BENIH, DAN PERTUMBUHAN BIBIT Magnolia champaca L.. *Iradiasi sinar gamma pada benih diketahui sebagai salah satu faktor yang dapat merangsang proses biokimia dan fisiologi. Tulisan ini menyelidiki pengaruh iradiasi terhadap perkecambahan, daya simpan benih, dan karakter pertumbuhan bibit* Magnolia champaca. *Benih diiradiasi dengan dosis 0, 5, 10, 15, 20, 40, 60, 80, dan 100 Gy dengan Cobalt-60. Benih-benih yang diiradiasi dibagi kedalam 3 kelompok perlakuan, yaitu untuk uji perkecambahan, uji penyimpanan, dan uji karakteristik pertumbuhan bibit. Pengamatan dilakukan untuk parameter daya berkecambah benih, indeks perkecambahan, waktu berkecambah rata-rata, nilai perkecambahan, dan karakter pertumbuhan bibit seperti tinggi, diameter pangkal akar, jumlah daun, panjang akar, dan berat kering total. Hasil penelitian ini menunjukkan bahwa iradiasi pada dosis 30 Gy diduga telah mencapai LD50, dan iradiasi pada dosis 80 Gy telah menyebabkan kematian sebagian besar benih. Peningkatan parameter perkecambahan benih tertinggi terjadi pada dosis 10 Gy, dan kemudian perkecambahan mengalami penurunan. Laju pertumbuhan dalam bentuk tinggi bibit, diameter pangkal akar, jumlah daun, dan berat kering total juga meningkat pada dosis iradiasi sinar gamma hingga 80 Gy, namun dosis 10 Gy menghasilkan persen hidup dan pertumbuhan yang lebih stabil dalam menghasilkan nilai tertinggi untuk sebagian besar parameter. Dengan demikian, perlakuan iradiasi dosis rendah (10 Gy) dapat digunakan untuk meningkatkan perkecambahan, daya simpan, dan pertumbuhan bibit* M. champaca.

Kata kunci: Magnolia champaca*, iradiasi gamma, perkecambahan, pertumbuhan*

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I. INTRODUCTION

Magnolia champaca (synonym *Michelia champaca* L. family: Magnoliaceae), locally known as cempaka kuning and bambang lanang, is a tree with golden-yellow fragrant flowers and aggregate fruits. This species is native to Indonesia, globally distributed in the Indo-Malaya ecozone. Within Indonesia it is distributed in Sumatra, Kalimantan, Sulawesi and the Lesser Sunda Islands (Sosef, Hong, & Prawirohatmodjo, 1998). This species produces timber for construction, furniture and plywood (Lukman, 2011; Kimho & Irawan, 2011) and various parts of the plant possess anti-inflammatory, antimicrobial, antioxidant and antimicrobial activities (Kumar, Kumar, Shashidhara, Anitha, & Manjula, 2011). In several areas such as South Sumatra and North Sulawesi, *M. champaca* is an important tree for cultivation. Propagation of *M. champaca* still has some problems due to poor seed storage and seedling viability. The seed propagation is time consuming (slow germination: 5 weeks to 4 months to germinate) and generally low percentage of germination and quick loss of viability (Zabala, 1990; Hossain & Nizam, 2002; Candiani, Galetti, & Cardoso, 2004). The species has been reported to be recalcitrant or intermediate due to its relatively short life span (Bisht & Ahlawat, 1999; Fernando, Jayasuriya, Walck, & Wijetunga, 2013). Chemical or physical seed treatments will be needed for enhancing germination. Gamma irradiation, one of the physical treatments, can be useful for altering its physiological characters (Kiong, Lai, Hussein, & Harun, 2008) and improving germination and seedling growth.

Gamma irradiation is one of the common practices to induce genetic variation in many plant species (De Micco, Arena, Pignalosa, & Durante, 2011; Moussa, 2011) including tree species (Iglesias-Andreu, Octavio-Aguilar, & Bello-Bello, 2012). It has a profound influence on plant growth and development by inducing genetical, cytological, biochemical, physiological and morphogenetic changes in cells and tissues depending on the levels of irradiation (Ikram, Dawar, Abbas, & Javed, 2010). The material and energy necessary for initial growth is already available in the seed, but some stimulants are required to activate those substances already stored in the cotyledons. Low doses of irradiation may increase the enzymatic activation and awakening of the young embryo, which results in stimulating the rate of cell division and affects not only the germination, but also the vegetative growth (Sjodin, 1962; Piri, Babayan, Tavassoli, & Javaheri, 2011).

The biological effect of gamma radiation is mainly due to the formation of free radicals by the hydrolysis of water, which may result in the modulation of an anti-oxidation system, accumulation of phenolic compounds and chlorophyll pigments (Wi et al., 2007; Ashraf, 2009). Treatment of tree seed with low dose gamma irradiation has been found to improve seed germination and seedling growth (Iglesias-Andreu et al., 2012). Enhancement of germination and growth along with plant metabolites, using irradiation technology, could be employed for improving the quality of seed, including their seedling growth. Furthermore, gamma irradiation has been applied to achieve a delay in the ripening of some fruits (World Health Organization & Food and Agriculture Organization of the United Nations, 1988), to reduce bacterial populations, fungi, insects and other germination pathogens (Gruner, Horvatic, Kujundzic, & Magdalenic, 1992) so it can be applied to increase the seed storability.

Despite the usefulness of ionizing irradiation to increase the germination potential and generating useful mutations in agricultural crops, there are not many references in the literature on the use of nuclear techniques on forest tree species (Iglesias-Andreu et al., 2012) because most of the seed germination studies of forest tree species were carried out by physical and/or chemical pre-sowing treatments. The irradiation techniques focused more to generate the variation for mutation breeding purposes. It is well known that the sensitivity of plants to irradiation are dependent on many factors such as plant species or varieties, plant parts, and irradiation dose (Esnault, Legue, & Chenal, 2010; De Micco et al., 2011). Hence, this paper investigates the effects of gamma rays on the germination of seeds, growth, and biochemical attributes of *M. champaca* seedlings.

II. MATERIAL AND METHOD

A. Materials

Mature fruits of *M. champaca* were collected from the identified seed source of Talang Pelawi, Muara Payang Village, Sub-district *Jarai*, District Lahat, South Sumatra in February 2011. The application of Cobalt-60 gamma irradiation (Gamma Chamber 4000A-Irpasena, India) was conducted at the Center for the Application of Isotope and Radiation Technology, National Nuclear Energy Agency, Jakarta, Indonesia. The seed germination and seedling growth tests were conducted at the Laboratory of Forest Tree Seed, Forest Tree Technology Research Institute, Bogor between March to September 2011.

B. Gamma Irradiation

Seeds were extracted based on wet extraction method as stated by Bonner, Fozzo, Elam, & Land, (1994) and the seeds were dried in room temperature to reach 10-12% moisture content. Fresh, uniform and healthy seeds were irradiated with 0, 5, 10, 15, 20, 40, 60, 80 and 100 Gy of gamma irradiation from Cobalt-60 (1 Gy = 100 rad) (Piri et al., 2011). The treated seeds in each dose were divided into three groups, germination test, storage test and seedling growth characteristics assessment.

C. Effect of Gamma Irradiation on Seed Germination and Seed Storage

For germination test, all the treated seeds were sowed on top of the straw paper in the germination box (IPB 73/1, Bogor Agricultural University). Each treatment was replicated four times with 50 seeds in each replicate and arranged in a randomized complete design.

Other treated seeds were stored in the refrigerator (temperature 4°C, relative humidity 40-50%) for 3 months. Seeds were packed in porous cloth bag. Each treatment was replicated four times with 50 seeds in each replicate and arranged in a randomized complete design. Similar parameters with germination test were measured for assessment of seed germination after storage.

The number of germinated seeds was counted every day. Final germination time was defined as the day when no further germination occurred for four successive days (Xu et al., 2016). Germination index (*GI*) and mean germination time (*MGT*) were calculated using the method of Czabator (1962), Ruan, Xue, & Tylkowska (2002) and Akinci & Akinci (2010). The germination value (*GV*) is an index combining speed and completeness of germination where larger values indicate faster and more complete germination (Czabator, 1962; M. A. Hossain, Arefin, Khan, & Rahman, 2005). The traits were calculated as follows:

$$GP = G/T \times 100 \quad (1)$$

$$GI = \Sigma(Gt/Tt) \quad (2)$$

$$MGT = \Sigma TtGt/\Sigma Gt \quad (3)$$

$$GV = (\Sigma DGs/N) \times GP/10 \quad (4)$$

where *GP* is the germination percentage at the end of experiment, *G* is the total number of germinated seeds, *T* is the number of sowed seeds, *Gt* is the number of newly germinated seeds on day *t* and *Tt* is the number of days, *DG* is the daily germination speed obtained by dividing the cumulative germination percentage by number of days since sowing, Σ*DGs* is the total germination obtained by adding every *DG* value obtained from the daily counts, *N* is the total number of daily counts starting from the first germination, and 10 is constant. The lethal dose 50 (LD50) was calculated following regression of the germination data per cent lethality over control of gamma rays doses (Singh & Balyan, 2009).

D. Effect of Gamma Irradiation on Seedling Growth

Subsequently, the irradiated seeds (fresh/ non storage seeds) of *M. champaca* and their corresponding controls were sowed separately under greenhouse conditions in germination boxes containing a mixture of forest soil and sand in a 1:1 volume/volume. After 40 days in the germination box, seedlings were transplanted into polythene bags (diameter 12 cm, height 15 cm) and arranged in a randomized block design with six replications. Twenty seedlings formed a square for each replication. When the seedlings were 6 months in the nursery, the seedlings were measured regarding height, root collar diameter, number of leaves, tap root length, above ground and belowground biomass, total biomass, and sturdiness quotient. For biomass measurements, all plants were harvested and divided into roots, stems and leaves. Roots, stems and leaves were dried separately in a drying oven at 70°C for 48 hours and weighed to ±0.0001 g. Leaves and stems were aggregated and are subsequently referred to as aboveground biomass and roots are referred to as belowground biomass. Total biomass is the sum of aboveground and belowground biomass. The sturdiness quotient is the height (*h*) in centimeters divided by the stem diameter (*d*) in millimeters (Thompson, 1985).

E. Data Analysis

The data were analyzed using IBM SPSS (v21) statistical software (SPSS Inc. Chicago, IL, USA) following a randomized, complete block design. The mean values were compared using Duncan's Multiple Range Test (DMRT) at 0.05% level of probability.

III. RESULT AND DISCUSSION

A. Effect of Gamma Irradiation on Seed Germination and Storability

The irradiated *M. champaca* seeds, both without and with storage in refrigerator for 3 months, have shown a significant increase in the germination percentage, germination index, mean germination time, and germination value compared to control, but then the parameters tended to decrease by increased irradiation doses (Table 1). Similar trend was reported by Iglesias-Andreu et al. (2012) in *Abies religiosa*, the percentage of germination increased with increased frequency of mutation up to 10 Gy and then decreased gradually with increased gamma ray dose. Habba (1992) in *Hyoscyamus muticus* seed reported that by increasing the dose of gamma rays it has gradually increased the germination percentage up to 100 Gy. Marcu, Cristea and Daraban (2013) and Bodele (2013) also reported increasing germination parameters in low doses of gamma ray irradiation as compared to untreated plants. Responses of increased doses of gamma rays on germination traits were different among species.

The maximum increase of germination percentage and germination index on irradiated fresh seeds of *M. champaca* was recorded at 10 Gy with an increment percentage of 9.4% from control for germination capacity and increment percentage of 30% from control for germination index. For storage of irradiated seeds, the maximum increase of germination capacity was also recorded at 10 Gy (increase 34.1% to control) and for mean germination time and germination value, an increase was observed up to 15 Gy, and then it decreased. For both irradiated fresh and stored seeds, the dose of 10 Gy showed the highest values for all germination parameters (Table 1 and 2). Aynehband and Afsharinafar (2012) reported a significant increase in the germination, which was the speed of emergence of seedlings, in three amaranth lines observed after pre-sowing irradiation treatment. However, the critical dose that increased seed germination varied among species and also ranged from genotype to genotype within species. In *Pterocarpus santalinus* a lower dose of 25 and 50 Gy significantly increased the germination index and vigor compared to the control (Akshatha & Chandrashekar, 2013).

Irradiation at dose higher than 30 Gy and below 40 Gy is considered being the lethal dosage (LD50) for *M. champaca* seeds (Table 1; Figure 1). Lethal dosage (LD50) is different for different species. Wegadara (2008) mentioned that LD50 of *Anthurium andreanum* seeds is lower than 40 Gy, while for *Amorphophallus*

Table 1. Effect of different doses of gamma irradiation on the germination of *Magnolia champaca* seeds

Doses (Gy)	Germination parameters			
	Germination percentage (%)	Germination index	Mean germination time	Germination value
0	53.67± 3.28 ab	1.67±0.08ab	12.69±3.74 a	0.078±0.021 a
5	49.33± 3.78 ab	1.81±0.14 ab	13.74±3.05 a	0.056±0.008ab
10	58.67± 2.66 a	2.17±0.11 a	16.17±2.83 a	0.078±0.007 a
15	46.00± 2.42 ab	1.70 ±0.11ab	11.36±3.19 a	0.048±0.005 b
20	35.00±10.12 b	1.26±0.38 b	8.37±4.91 a	0.038±0.015 b
40	13.00± 6.46 c	0.42±0.21 c	5.45±5.11 a	0.007±0.006 c
60	12.67± 5.64 c	0.42±0.19 c	6.49±5.33 a	0.006±0.004 c
80	9.33± 4.91 c	0.30±0.16 c	6.18±5.76 a	0.004±0.003 c
100	5.33± 1.83 c	0.16±0.05 c	6.46±5.91 a	0.001±0.001 c
F-test	14.045**	35.312**	0.659ns	11.377**

Remarks: The data shown are mean ± standard error of six replicates; Different letters a, b, c, d and ab denote significant difference (P ≤0.05) between different treatments; ** = Significant at P <0.01; ns = not significant.

muelleri, irradiation at a dose higher than 10 Gy and below 20 Gy is considered the lethal dosage (LD50) (Santosa, Pramono, Mine, & Sugiyama, 2014). According to Soeranto (2015), doses between LD20 (between 15-20 Gy in this study) and LD50 are considered as optimal doses for increasing the variation especially used for mutation breeding program, and in low doses, the irradiation has stimulatory effects. A radiostimulant low-dose is defined as any dose from environmental radiation level and the threshold that marks the boundary between positive and negative biological effect (Iglesias-Andreu et al., 2012).

Improvement in seed germination at lower doses of gamma radiation was also observed on *Tectona grandis* (Bhargava & Khalatkar, 1987), *Acacia leucophloea, Albizia lebbeck*, *Zizyphus mauritiana* (Selvaraju & Raja, 2001), *Pterocarpus santalinus* (Akshatha & Chandrashekar, 2013), and *Terminalia arjuna* (Akshatha, Chandrashekar, Somashekarappa, & Souframanien, 2013). The stimulating effect of low dose gamma ray on germination may be attributed to the activation of RNA synthesis, or protein synthesis (Kuzin, Vagabova, & Revin, 1976) which occurred during the early stage of germination. Gamma rays are ionizing radiation having low wavelength with high penetrable power, interact with atoms or molecules to produce free radicals in the cells. The free radicals can damage or modify components of plant cells. It has been reported to affect seed germination, morphology, anatomy, and physiochemical characteristics of plants, depending on irradiation level (Maamoun, El-Mahrouk, Dewir, & Omran, 2014). Whereas higher doses of gamma rays affected to inhibit the germination. Hell and Silveira (1974) stated that on *Phaseolus vulgaris*, treating seeds with high rates of gamma radiation reduced germination. Kumar and Mishra (2004)) reported that in okra (*Abelmoschus esculentus*) germination percentage generally decreased with increasing doses of gamma rays. Reduced germination percentage with increasing doses of gamma radiation has also been reported in *Pinus* (Thapa, 2004) and *Cicer arietinum* (Khan, Qureshi, Hussain, & Ibrahim, 2005). Yusuf and Nair (1974) inferred that gamma irradiation interfered with the synthesis of enzymes and at the same time accelerated the degradation existing enzymes involved in the formation of auxins and thus

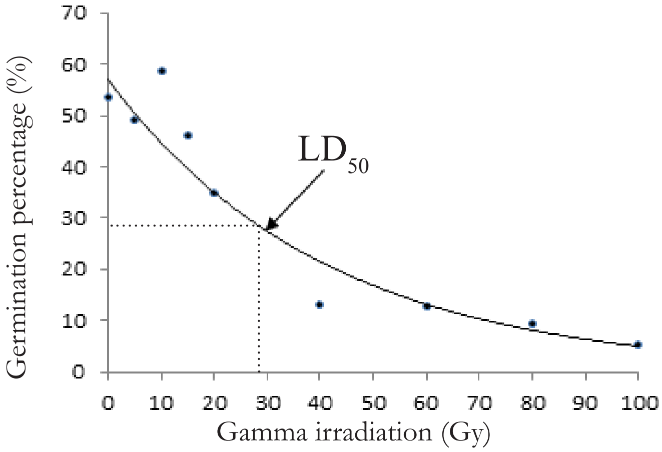

Figure 1. LD50, 50% seed germinated after gamma irradiation treatment

reduced the germination of seeds. Reduced seed germination due to mutagenic treatments may might be as a result of the damage of cell constituents at molecular level or altered enzyme activity (Khan & Goyal, 2009).

The irradiation of gamma rays also improved the storability of *M. champaca* seeds. The irradiated seeds that were stored for 3 months had better germination than control up to 20 Gy, and then tended to decrease thereafter (Table 2). Gamma irradiation has a long-term beneficial effect on the integrity and function of the plasma membrane of hypodermal mesocarp tissue. The long-term beneficial effects of irradiation included greater retention of total plasma membrane protein, a diminished decline in total plasma membrane phospholipids and in the phospholipid: protein ratio, and maintenance of a greater overall H+-ATPase activity (Lester & Whitaker, 1996). Irradiation was also effective to reduce the attack of a number of biological agents (microorganisms, rodents, and insects) causing the losses in the quality and quantity of the stored seeds (Darfour, Ocloo, & Wilson, 2012), so the low dose irradiation could improve seed storability.

There was no big difference in seed germination between *M. champaca* fresh (unstored) seeds and stored seeds. Based on the International Standard Testing Association tolerance value between two germination tests,the germination capacity of fresh and stored seeds, was within the tolerance level. The germination capacity between 42% and 59% has the tolerance value (differential value between two germination tests) of 11% (The International Seed Testing Association, 2011). In this testing, the germination capacities of the control fresh and stored seeds were 55% and 44%, respectively. On the other hand, the mean moisture content of fresh seeds was 12.2% (after drying in room temperature) and it was not significantly reduced during 3 months of storage in the refrigerator (moisture content 11.4%). In a graph of seed weight vs seed moisture content, *M. champaca* was plotted between the orthodox and recalcitrant species but closer to orthodox (Hong & Ellis, 1995). Result of this research indicates that *M. champaca* seeds storage behavior may be best classified as intermediate. Although some researcher (Bahuguna, Rawat, & Naithani, 1987) reported that the seeds of M. champaca are short-lived, but the loss of viability can be minimized by moist storage especially at low temperatures (4°C) for up to 9 months (Bisht & Ahlawat, 1999).

B. Effect of Gamma Irradiation on Seedling Growth

Table 3 presents the growth traits of *M. champaca* seedlings, both for the control and irradiated fresh (unstored) seed samples. The

Table 2. Effect of different doses of gamma irradiation on the germination of stored seed for 3 months

Doses (Gy	Germination parameters			
	Germination percentage (%)	Germination index	Mean germination time	Germination value
0	44.00±1.46 bcd	1.67±0.05 a	15.68±2.42 ab	0.89±0.16 c
5	49.00±4.97 abc	1.67±0.17 a	12.87±3.72 ab	1.00±0.23 bc
10	59.33±1.60 a	1.97±0.05 a	21.24±1.98 a	2.15±0.11 a
15	50.00±3.86 abc	1.66±0.13 a	18.92±2.26 a	1.56±0.23 ab
20	52.33±2.02 ab	1.72±0.07 a	17.98±2.89 a	1.68±0.12 a
40	45.00±5.92 bcd	1.68±0.23 a	8.19±4.39 a	0.44±0.01 b
60	37.67±8.08 d	1.12±0.25 b	11.75±4.91 ab	1.06±0.33 bc
80	0.33±0.33 e	0.01±0.01 c	5.50±5.50 bc	0.00±0.00 d
100	0.33±0.33 e	0.01±0.10 c	0.00±0.00 c	0.00±0.00 d
F-test	14.307**	37.359**	3.855*	16.070**

Remarks: The data shown are mean±standard error of six replicates; Different letters a, b, c, d and ab denote significant difference (P≤0.05) between different treatments; ** = Significant at P <0.01; * = Significant at P <0.05.

use of irradiated fresh seeds represented the assessment of the effect of all gamma irradiation treatments on seedling growth rather than irradiated stored seeds because on the irradiated stored seed, for some treatments (80 and 100 Gy), the germination percentage was near 0% (0,33%). There were not enough seedlings for growth analysis.

The statistical analysis showed that the growth traits were affected by the dose of gamma rays, except for root length. The seeds irradiated with 5, 10, and 15 Gy have shown significant increase in the seedling survival compared to the controls, with the highest being observed at 5 Gy (Table 3). The seedling survival continuously decreased after 20 Gy. According to Nazir, Mohamad, Affida, and Sakinah (1988), if the doses were too high, too many plants would be killed because mutagens could have direct negative effect on plant tissue and many mutations could be lethal. This was due to the fact that primary injuries are retardation or inhibition of cell division, cell death affected the growth habit and changes in plant morphology. Conversely, the high dose of gamma irradiation induced the mutation in plants (Piri et al., 2011) produced new gen combination caused increase in variation. In this research, it can be shown in plant growth that varied more in seedling height and root collar diameter.

Increase seedling height was clearly evident and the maximum increase to the control was 77% at 80 Gy and it was not significantly different with doses of 10, 60, and 5 Gy with maximum increase of 75%, 65%, and 61%, respectively (Table 3). Although the dose of 80 Gy revealed as the highest mean of seedling height, the dose just provided low seedling survival (18%) with high variation in seedling height (higher standard error). The higher doses of gamma irradiations (>60 Gy) were generated more genetic variations as shown by the relative higher standard error.

Performance of *M. champaca* seedlings at 6 months age grown from irradiated seed at doses 0, 5, and 10 Gy was more uniform in each treatment and the dose of 10 Gy showed the best performance (Figure 2). Sakin (2002) stated that gamma ray irradiation treatment increased the average plant height compared with controls. In fact, many researchers have reported the effect of ionizing radiation on growth and morphology in different plant species (De Micco et al., 2011; Piri et al., 2011; Iglesias-Andreu et al., 2012). For seedling collar

Table 3. Effect of gamma irradiation on seedling survival and growth traits (mean ± standard error) of *M. champaca* seedlings at 6 months

Doses (Gy)	Survival (%)	Height (m)	Root collar diameter (cm)	Root length (cm)	Leaf number	Aboveground biomass (g)	Belowground biomass (g)	Total biomass (g)
0	47.64±2.39 b	17.05±0.71 b	3.14±0.11 b	23.7±2.35 a	11.4±0.65 b	1.67±0.23 bc	0.58±0.07 ab	2.26±0.29 abc
5	55.54±2.39 a	28.14±0.76 a	3.97±0.11 a	19.1±2.97 a	13.0±0.42 b	2.19±0.40 abc	0.69±0.09 ab	2.89±0.29 abc
10	53.27±2.04 a	29.88±1.03 a	4.17±0.14 a	17.8±2.16 a	11.9±0.63 b	4.25±0.09 a	0.65±0.07 ab	4.91±0.19 a
15	54.54±2.39 a	27.48±1.23 ab	3.38±0.11 a	17.7±2.28 a	11.6±0.59 b	1.81±0.16 abc	1.02±0.07 a	2.84±0.42 abc
20	47.64±2.39 b	24.47±1.21ab	3.68±0.15 ab	25.5±3.92 a	12.8±0.78 b	2.11±0.20 abc	0.70±0.06 ab	2.16±0.25 bc
40	29.19±1.25 c	24.33±1.20 ab	3.76±0.23 ab	18.6±1.99 a	11.4±0.53 b	1.61±0.31 bc	0.55±0.09 ab	2.17±0.39 abc
60	23.60±2.04 d	28.22±2.35 a	3.95±0.29 a	20.9±2.89 a	14.3±1.11 a	3.65±0.64 ab	0.97±0.18 a	4.63±0.82 ab
80	18.22±1.44 e	30.32±2.11 a	4.11±0.25 a	23.5±3.27 a	12.8±1.14 b	2.21±0.24 abc	0.53±0.65 ab	2.75±0.30 abc
100	10.08±1.44 f	20.33±3.79 b	3.65±0.43 b	20.8±1.63 a	8.8±0.82 c	0.53±0.23 c	0.27±0.81 b	0.80±0.31 c
F-test	122.711**	21.383**	6.616**	1.083ns	3.672**	1.987*	1.491*	2.200*

Remarks: The data shown are mean ± standard error of six replicates; Different letters a, b, c, d and ab denote significant difference ($P \leq 0.05$) between different treatments; ** = Significant at $P < 0.01$; * = Significant at $P < 0.05$

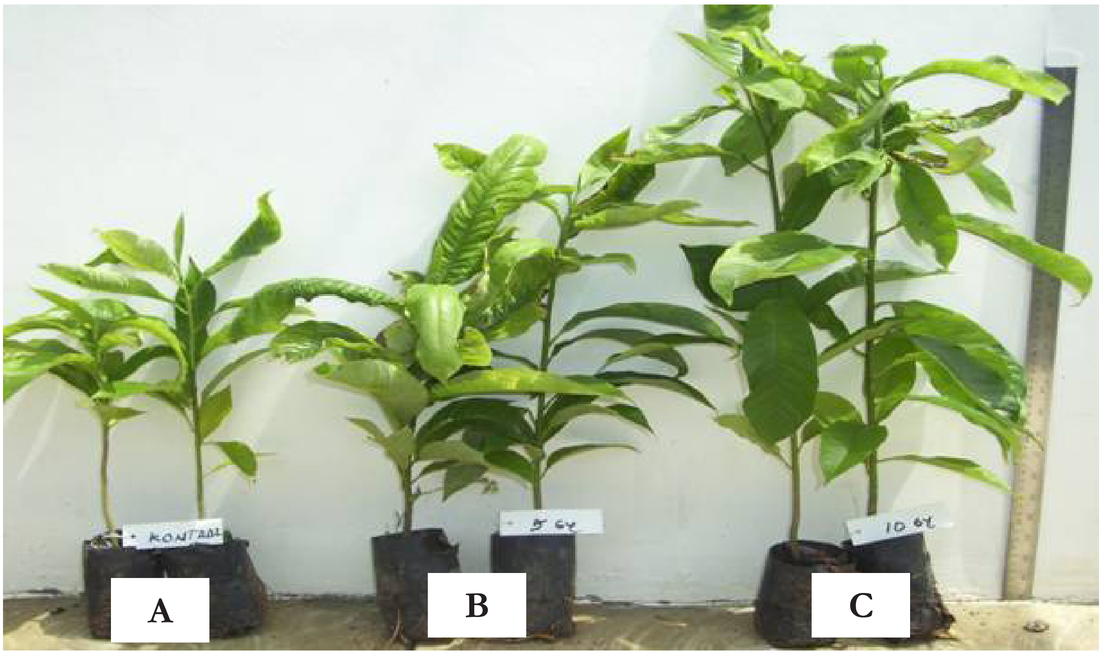

Figure 2. Performance of *Magnolia champaca* seedlings at 6 months age grown from irradiated seeds at doses 0 (A), 5 (B), and 10 Gy (C)

diameter, the maximum increase compared with control was 32% at 10 Gy and it was not significantly different with 5, 15, 60 and 80 Gy. The maximum increase of number of leaves was at 60 Gy. Dry weights of the seedlings were found to be significantly higher at 10 Gy (Table 3). This result was similar with Sherif, Khattab, Ghoname, Salem, and Radwan (2011) on *Hibiscus sabdariffa* that observed a significant increase in dry weight of the whole plant grown by irradiated seeds with low doses. Generally, the growth traits of *M. champaca* in this research decreased after 80 Gy. Villavicencio, Mancini-Filho, and Delinciee, (1998) stated that the critical dose that prevented growth varied among species and also ranged from genotype to genotype within species. In *Pinus kesiya* and *P. wallichiana*, an increased dose of radiation above 100 Gy reduced the shoot epicotyls and the root primordia, indicating its sensitivity toward the gamma rays (Thapa, 2004). However, *M. champaca* was found to be more sensitive to ionizing radiation. This result provided the expectation to solve the problem of seed germination, especially for improving the storability of *M. champaca* seeds that was categorized as intermediate seed with low storability.

IV. CONCLUSSION

Enhanced germination percentage, germination index, mean germination time, and germination value were observed in the low dose gamma irradiations of *M. champaca* seeds. The maximum increase of germination percentage on irradiated fresh seed of *M. champaca* was recorded at 10 Gy (increase 9.4% to control), while for storage of irradiated seed, the maximum increase was also recorded at 10 Gy (increase 34.1% to control). The seeds had LD50 close to 30 Gy, LD20 is about 15-20 Gy, and irradiation at doses of 80 Gy and higher caused lethal effect. Low dose gamma irradiation also improved the storability of the seeds. The optimum treatment for improving the seed germination and storability of *M. champaca* is 10 Gy. Growth rate in terms of seedling height, collar diameter, number of leaves, and dry weight have also increased in gamma irradiation doses up to 80 Gy. However, the growth traits were more stable and hadthe highest performances on seedling survival and growth at the dose of 10 Gy. Based on these results, it might be concluded that lower doses (10 Gy) of radiation might facilitate better seed germination, storability and seedling growth of *M. champaca*. This technique could be used for improving the seed and seedling quality to support the seedling procurement for establishing plantation forests.

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