American Journal of Animal and Veterinary Sciences

Original Research Paper

Radiosensitivity Assessment and the Impact of Gamma Radiation on the Growth and Diversity of *Pennisetum purpureum* Cv Mot in Marginal Land

[1]**Bela Putra and** [2]**Budi Prasetya**

[1]*Department of Animal Science, Faculty of Agriculture, Universitas Muara Bungo, Jambi, Indonesia*
[2]*Department of Agros Science, Faculty of Agriculture, Universitas Muara Bungo, Jambi, Indonesia*

Article history
Received: 17-09-2023
Revised: 06-11-2023
Accepted: 15-11-2023

Corresponding Author:
Bela Putra
Department of Animal Science,
Faculty of Agriculture,
Universitas Muara Bungo,
Jambi, Indonesia
Email: belaputramsc@gmail.com

Abstract: This study aims to assess the radiosensitivity of *Pennisetum purpureum* cv Mott, with the primary objectives of determining the LD50 value, evaluating the effects of gamma radiation doses on plant growth and diversity, and elucidating the specific goals of irradiation in relation to the overall research. The research encompasses a wide range of radiation doses, ranging from 0-400 Gy, including multiple double doses (×2 Gy). The investigation involved irradiating *Pennisetum purpureum* cv Mott seeds (cuttings) and observing their seed germination capacity after one month. This research was conducted with rigorous scientific methodology, involving five replicates, each consisting of 100 plants. The study was carried out in marginal land conditions with a pH range of 4.5-5. These specific experimental conditions were chosen to simulate real-world scenarios and provide valuable insights into the radiosensitivity of *Pennisetum purpureum* cv Mott under conditions similar to those found in marginal agricultural areas. It is noteworthy that this study represents a novel contribution to the field of radiosensitivity in plants, as it differs significantly from previous research endeavors. This research offers a fresh perspective and distinctive findings that set it apart from prior studies. In addressing ethical standards, it is essential to note that this study strictly adhered to ethical considerations, particularly regarding the use of radiation on plants. All procedures were carried out in accordance with established ethical guidelines and compliance with radiation safety protocols. The findings reveal that radiation doses significantly influence seed germination and the morphology of leaves, stems, and roots in *Pennisetum purpureum* cv Mott. The study indicates that the Lethal Dose 50 (LD50) for *Pennisetum purpureum* cv Mott is approximately 28.79 Gy. Furthermore, a diverse range of traits, including leaf count, leaf length, plant height, stem length, and stem diameter, exhibit varying degrees of heritability, with coefficients of genetic variation (KKG) ranging from low to very high. In conclusion, this comprehensive and novel study sheds light on the impact of gamma radiation doses on *Pennisetum purpureum* cv Mott. The results are instrumental in understanding the radiosensitivity of this plant species and hold potential applications in agronomy, especially in marginal land cultivation. Furthermore, this research contributes to a deeper understanding of radiation effects on plants, specifically within the context of *Pennisetum purpureum* cv Mott in marginal land conditions while adhering to ethical standards and introducing novel insights into the field.

Keywords: Germination Capacity, Radiation Dose, Lethal Dose, *Pennisetum purpureum* Cv Mott, Radio Sensitivity

Introduction

The success of ruminant livestock farming and development hinges on the availability of high-quality forage, which serves as the primary source of nutrition for these animals, providing essential nutrients for their well-being. Wu *et al*. (2023) reported that forage has a significant contribution to goat fattening. The significant role of forage in determining the success of ruminant livestock development makes it crucial to enhance the quality of forage. Climate change also determines the changes in the quality of various forages, which have the potential to affect livestock development (Tamboli *et al*., 2023) emphasized that in order to protect the animals on the farm from environmental stress, it is necessary to provide them with a nutritious diet, proper healthcare and employ other effective management strategies.

However, a significant challenge in the development of high-quality forage is the scarcity of available land for cultivation. The conversion of agricultural land for non-agricultural purposes further diminishes the area suitable for forage production. One promising solution to address this issue is the utilization of marginal lands. Indonesia, as a country endowed with vast expanses of marginal lands, presents an opportunity to explore this alternative. These marginal lands often possess acidic soil conditions, encompassing approximately 69.4% of the nation's total land area, equivalent to 108.8 million hectares (Mulyani and Sarwani, 2013). The predominant acidic soil types in Indonesia include entisol, utisol, inceptisol, spodosol, and oxisol, with inceptisol and utisol being the most prevalent acidic soil types found in regions such as Papua, Kalimantan, and Sumatera (Mulyani and Hikmatullah, 2004).

While increasing fertilizer usage and implementing various technological applications have been proposed to improve livestock forage productivity on marginal lands, these approaches often come with substantial production costs. An alternative and cost-effective approach is the development of forage plant varieties specifically adapted to thrive on marginal lands. This necessitates active breeding programs focused on enhancing forage plant characteristics, with the potential to increase productivity by over 50% (Yulia *et al*., 2022).

Plant breeding programs offer a promising avenue to enhance both the quantity and quality of forage plant varieties. This process involves the deliberate modification of plant characteristics, leading to the development of new traits that surpass those of the original plant. These improved traits can encompass resistance to pests and diseases, resilience to environmental stressors, increased yields, and improved nutritional content (Su *et al*., 2015).

Pennisetum purpureum cv. Mott is a grass variety characterized by robust root systems, non-hardened stems, numerous leaf nodes, and foliage that is readily consumed by livestock. Previous research by Ananta *et al*. (2019) reported the dry matter and crude protein contents of 13.96-12.58%, respectively, in *Pennisetum purpureum* cv. Mott. Despite these promising attributes, this forage variety is plagued by low productivity (Utomo *et al*., 2021). Furthermore, *Pennisetum purpureum* cv. Mott has found utility in phytoremediation, specifically in soils contaminated with substances such as Arsenic (As) (Chouychai and Somtrakoon, 2022; Kowitwiwat and Sampanpanish, 2020) and heavy metals (Putra *et al*., 2022), However, it exhibits limitations in adapting to saline soil conditions (Pongtongkam *et al*., 2006) and faces challenges related to biomass production and root growth in acidic soils (Putra *et al*., 2022; Kowitwiwat and Sampanpanish, 2020) reported reduced chlorophyll content in *Pennisetum purpureum* cv. Mott when grown in tailing soil contaminated with heavy metals. These limitations stem from the acidic soil pH, which adversely affects growth.

Addressing these challenges involves the development of plant varieties capable of tolerating acidic soil conditions through plant breeding programs. The effective utilization of gamma radiation mutagen, as emphasized by Syukur *et al*. (2011), is a crucial aspect of this breeding process. Plant breeding endeavors aim to generate superior individuals capable of thriving in diverse environmental conditions, with mutation breeding standing out as one of the most effective methods for enhancing specific traits (Harsanti and Dewi, 2013). Mutations, when strategically induced, can significantly improve inherent plant traits (Shu *et al*., 2012). making mutation breeding a powerful tool for addressing undesirable plant characteristics (Yali and Mitiku, 2022).

Radiosensitivity assessment, involving exposure to gamma radiation, is a pivotal method for determining optimal dosages to induce mutations. This assessment relies on the physiological response of plant material to radiation, including the determination of lethal doses (LD20 and LD50), which correspond to the radiation doses causing a 20-50% mortality rate, respectively. In mutation induction, the dosage range that usually yields the highest diversity and number of mutants falls within the LD20-LD50 range. Beyond LD50, radiosensitivity can also manifest as growth inhibition, lethality, somatic mutations, chromosomal breaks, and variations in the number and size of chromosomes. It is important to note that radiosensitivity levels vary depending on plant species, varieties, physiological conditions, and plant organs involved (Aisyah *et al*., 2009).

Given the variation in radiosensitivity across plant species and cultivars, there is a compelling need to conduct experiments specifically to determine radiosensitivity in *Pennisetum purpureum* cv. Mott. This research endeavor is distinctive in that it aims to establish LD20-LD50 values for *Pennisetum purpureum* cv. Mott is grown and adapted in Indonesia, using genetic material sourced from seeds. Unlike previous studies on radiosensitivity in Bermuda grass, which utilized genetic material from plantlets

DOI: 10.3844/ajavsp.2024.20.30

(Pongtongkam *et al*., 2006). this research seeks to ascertain radiosensitivity in *Pennisetum purpureum* cv. Mott, a critical step in identifying the optimal radiation dosage required to enhance genetic diversity. Ultimately, the goal is to leverage induced mutation breeding in *Pennisetum purpureum* cv. Mott to develop desired cultivars aligned with specific breeding objectives.

Materials and Methods

Study Area

This research was conducted in Kota Baru Santan, Tubei, Lebong Regency, Bengkulu, Indonesia, at coordinates latitude -3.1667240 and longitude 102.1432690, with an elevation of 97 meters above sea level. The precise location is illustrated in Fig. 1.

Procedures

The research methodology encompassed the following stages.

The Radiosensitivity of Pennisetum purpureum Cv. Mott

The radiosensitivity study of *Pennisetum purpureum* cv. Mott involved subjecting it to gamma radiation treatment, a process that requires careful consideration due to its delicate nature and the adherence to multiple regulations and official authorizations (No: 202/KA/X/2012). Radiation treatment was carried out at BATAN (National Nuclear Energy Agency). *Pennisetum purpureum* cv. Mott seeds were exposed to acute doses of gamma radiation, including doses of 0, 5, 10, 15, 20, 25, 30, 50, 100, 150, 200, 250, 300, 350, 50, 100, 150, 175 and 200 x 2 Gy, with a control group. Cobalt 60 was the gamma radiation source administered through a gamma chamber irradiator model 4000 A. Each radiation dose was applied to 100 plant stems, resulting in a total of 1100 irradiated stems, with an additional 100 stems serving as the control group.

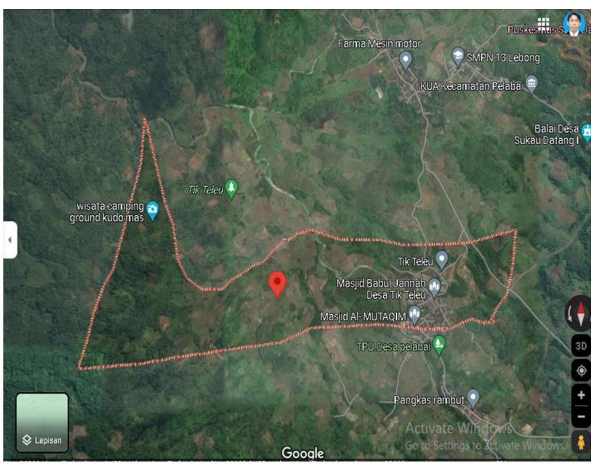

Fig. 1: The research was conducted at coordinates Lat 3.1667240 and Long 102.1432690, at an elevation of 97 m above sea level

Subsequently, the seeds were planted in pots containing normal soil and the percentage of seedling germination was evaluated four weeks after planting. The following variables were observed: (1) Percentage of seedling germination, (2) Number of leaves, and (3) Seedling height, measured from the base of the root to the tip of the seedling. The data on the percentage of seedling germination were used to calculate the Lethal Dose 50 (LD50), analyzed using the Curve-fit analysis program.

Identification of Mutant 1 (M1) in Marginal Land

Field research was conducted on marginal land in Kota Baru Santan, Tubei, Lebong Regency, Bengkulu, Indonesia, with coordinates latitude -3.1667240 and longitude 102.1432690. The research land had a pH range of 4.5-5.6 and an Aldd content of 2.26 ppm with 10.68% Al saturation. The experimental design employed a Randomized Complete Block Design (RCBD) with four replications. The treatment involved irradiation doses ranging from 20-LD50, including doses of 0, 5, 10, 15, 20, 25 and 30 Gy. The irradiation treatment was conducted at BATAN (National Nuclear Energy Agency).

The irradiated *Pennisetum purpureum* cv. Mott seeds comprised 100 seeds for each dose. Subsequently, 100 seeds for each dose were planted and grown on marginal land. The experimental unit consisted of approximately 700 plants. The land was prepared one week before transplanting the plants to the field. Plant maintenance was carried out according to the plant's developmental stage, which occurred at 2 months of age. Each individual plant was then harvested for growth and agronomic diversity analysis. Various characteristics were observed, including plant height, number of tillers, fresh green weight, leaf fresh weight, stem fresh weight, leaf length, leaf width, stem height, node length, and stem diameter.

Broad-sense heritability was calculated based on the obtained values (Kalton *et al*., 1952) using the formula:

$$h^2 = \frac{\delta^2\, S1 - \delta^2\, S0}{\delta^2\, S1}$$

where, $\sigma^2\ S0 = \sigma^2 c$ = among-offspring variance; $\sigma^2\ S1$ = variance of selfing progenies or mutations from offspring.

The stability value of putative mutant *Pennisetum purpureum* cv. Mott was also calculated. Although this is rarely performed on vegetatively propagated plants, it becomes necessary when variability results from mutational treatments. This is done to anticipate the occurrence of diplontic selection, which involves competition between mutant cells and the normal cells surrounding them (Hemerly *et al*., 1995):

$$\delta^2 \sum_{i=1}^{n} \left(\frac{(Xi - X)^2}{n}\right) =$$

$\sigma 2$ = varians atau ragam, xi = titik tengah, $\bar{x}$ = rata-rata, dan n = Jumlah data.

Data Analysis

The research data were analyzed for variance based on a randomized complete block design with seven treatments and four replications. Further analysis utilized Duncan's multiple range test to determine differences among the treatments.

Results and Discussion

Radiosensitivity of Pennisetum purpureum Cv. Mott

Observation of radiosensitivity in this study was conducted by observing the Lethal Dose 50 (LD50) of irradiated *Pennisetum purpureum* cv. Mott. The observations were made when the plants were one month old after irradiation and then the percentage of plant mortality was calculated. The observation results were calculated and analyzed using curve-fit, from which a mathematical equation was obtained (Fig. 2) representing the model mathematics used to estimate the LD50. Apart from determining the level of sensitivity to physical or chemical mutagens, the range of LD50 doses is also useful for estimating the appropriate dose or concentration to induce mutations (Abdullah *et al*., 2009).

The research on radiosensitivity in *Pennisetum purpureum* cv. Mott is an effort to understand the extent to which this plant is vulnerable to gamma radiation exposure and to calculate the LD50 value, which is the radiation dose that causes the death of 50% of the tested plants. In this study, the experimental data has been analyzed using a sinusoidal fit model represented by the following mathematical equation: Sinusoidal Fit Model: $Y = 82.13-9.00 \sin(-0.49 X +28.13)$. In this equation; Y is the measured response (in this case, the probability of plant death). X is the gamma radiation dose given to the plants. The sinusoidal fit model is used to describe the relationship between gamma radiation dose and the probability of plant death in *Pennisetum purpureum* cv. Mott. In this model, there are several parameters that have specific meanings, where Y Intercept (82.13) is the response value (probability of plant death) when the gamma radiation dose (X) is equal to zero. In this context, this value may represent the probability of plant death under control conditions without radiation. It's important to note that (Fig. 2) represents the mathematical model used for LD50 estimation.

Morphological Leaf Characteristics of Pennisetum purpureum Cv Mot Generation M1 in Marginal Land

As evident from the data, leaf length, leaf width, leaf area, and leaf fresh weight exhibit a pronounced response to gamma irradiation. Notably, at a dose of 30 Gy, these leaf characteristics are at their lowest, signifying that higher doses of gamma irradiation induce a significant reduction in leaf morphology. These findings are consistent with prior research conducted on gamma irradiation-induced mutations in various plant species, such as millet (Ambavane *et al*., 2015), soybean as well as corroborated by recent studies (Fallah *et al*., 2022; Owis *et al*., 2023).

However, a nuanced observation arises from the lack of significant difference at a dose of 25 Gy for leaf length and leaf weight ($p>0.05$). This suggests a potential threshold effect or nonlinear response to gamma irradiation within this dosage range. It is essential to recognize that genetic factors play a pivotal role in determining how a plant responds to stressors. Hou *et al*. (2023) reported that genes related to osmoregulation and antioxidation play important roles in the response of Trollius chinensis. Some genotypes may exhibit higher resilience and adaptive capacity, leading to non-significant differences at specific doses, while others may be more susceptible, resulting in significant variations in leaf morphology.

The interplay between genetic factors and radiation-induced stress is intricate and understanding the genetic mechanisms underlying these responses is critical. Further investigation into specific genetic markers or pathways associated with radiation tolerance or susceptibility can shed light on the genetic basis of these observations. This knowledge holds promise for future breeding programs aimed at developing radiation-resistant crop varieties, a crucial consideration in regions vulnerable to radiation exposure. The results presented in (Fig. 3) emphasize the intertwined relationship between genetic factors and the response of *Pennisetum purpureum* cv Mot leaves to gamma irradiation. The intricate interplay between genetic traits and radiation-induced stressors shapes the plant's morphological characteristics, offering valuable insights into plant adaptation mechanisms and potential avenues for genetic improvement.

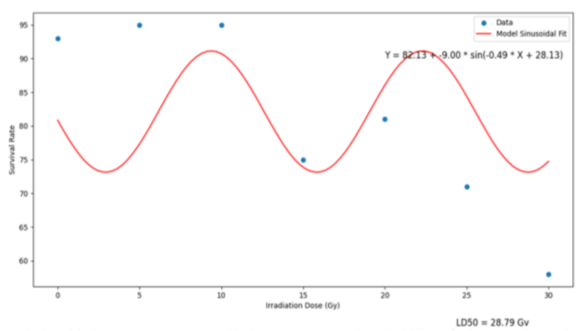

Fig. 2: Relationship between gamma radiation dose (X) and probability of plant death (Y) based on curve-fit analysis

DOI: 10.3844/ajavsp.2024.20.30

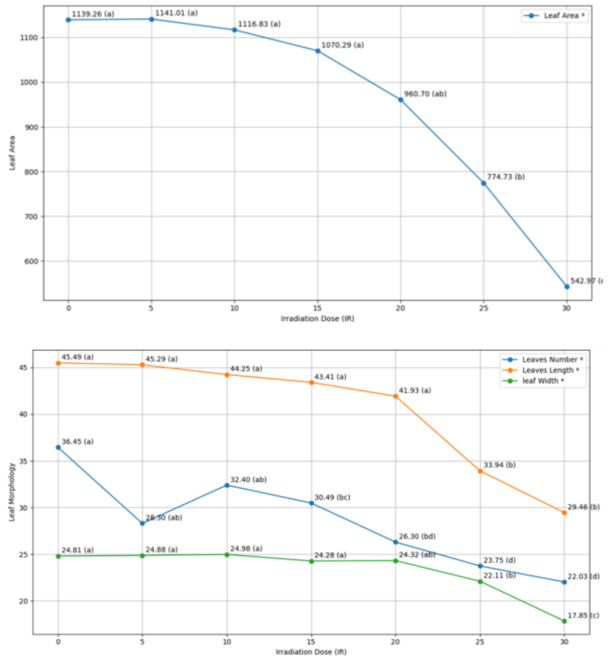

Fig. 3: The effect of irradiation doses on the morphology of *Pennisetum purpureum cv* mot leaves

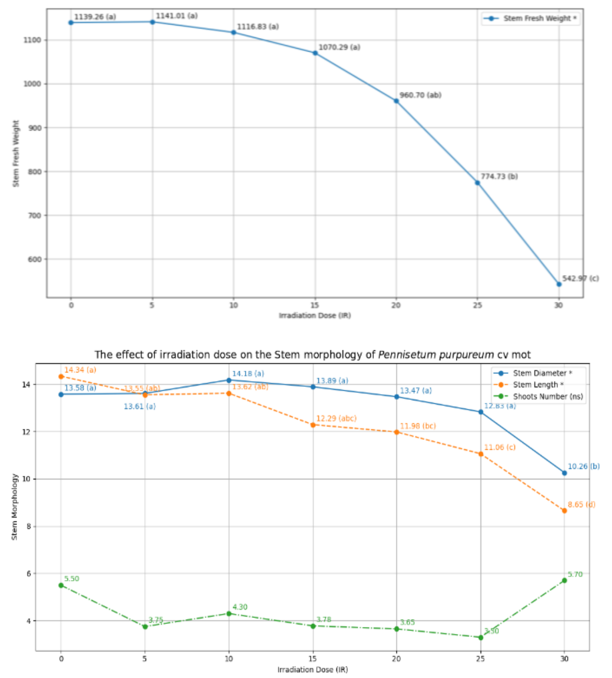

Fig. 4: The Effect of irradiation dose on the stem morphology of *Pennisetum purpureum* cv Mot

Morphological Characteristics of Pennisetum purpureum Cv Mot Stems in M1 Generation on Marginal Land

Figure 4 presents a comprehensive overview of the morphological characteristics of *Pennisetum purpureum* cv Mot stems in the M1 generation, cultivated on marginal land and subjected to varying doses of gamma irradiation. These observations provide critical insights into how genetic factors interplay with external stressors to mold stem morphology.

The outcomes of this study are striking, as they reveal that gamma irradiation doses exert a substantial influence on stem length, stem diameter, and stem fresh weight. Notably, the lowest values for these stem characteristics are observed at a dose of 30 Gy, signifying that higher doses of gamma irradiation lead to a significant reduction in stem morphology. Singh *et al*. (2023) observed a negative correlation between plant height and gamma radiation levels, which may be attributed to alterations in chromosomal structure and genetic composition. This aligns seamlessly with prior research conducted by Widoretno *et al*. (2023), which also demonstrated that gamma rays can inhibit the growth of vetiver grass stems. These findings reinforce the notion that radiation-induced stress can have a profound effect on plant stems, a phenomenon that transcends species boundaries.

It is worth highlighting the intriguing observation that, similar to leaf characteristics, there is no significant difference at a dose of 25 Gy ($p>0.05$) for both stem length and stem fresh weight. This non-significant difference at 25 Gy suggests that a threshold or nonlinear response may exist within this dosage range. Importantly, this underscores the intricate role played by genetic factors in mediating a plant's response to stressors like gamma irradiation. Some genotypes may exhibit greater resilience within this specific range, resulting in non-significant variations, while others may demonstrate more susceptibility, leading to significant differences in stem morphology.

The interplay between genetic factors and radiation-induced stress in stem development is multifaceted. Further exploration into the specific genetic mechanisms and regulatory pathways governing stem responses to radiation is warranted. Identifying key genetic markers associated with radiation tolerance or sensitivity can provide invaluable insights into the genetic underpinnings of these observations. This knowledge is pivotal for guiding future breeding programs aimed at cultivating crop varieties with enhanced radiation resilience, particularly in regions where radiation exposure is a concern.

Figure 4 underscores the intricate relationship between genetic factors and the response of *Pennisetum purpureum* cv Mot stems to gamma irradiation on marginal land. The profound impact of radiation-induced stress on stem morphology unveils the complex interplay between genetic traits and external stressors. These findings offer valuable insights into the mechanisms of plant adaptation and open up avenues for genetic enhancement to cultivate radiation-resistant crop varieties, addressing a critical need in regions susceptible to radiation exposure.

DOI: 10.3844/ajavsp.2024.20.30

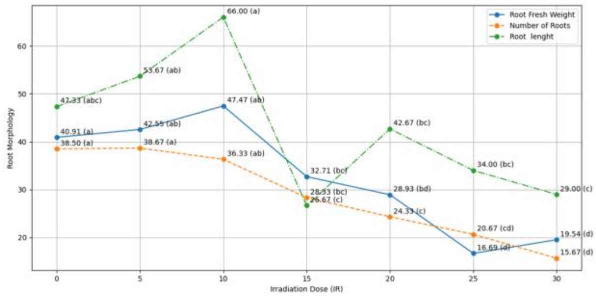

Fig. 5: The effect of irradiation dose on the root morphology of *Pennisetum purpureum* cv. Mot

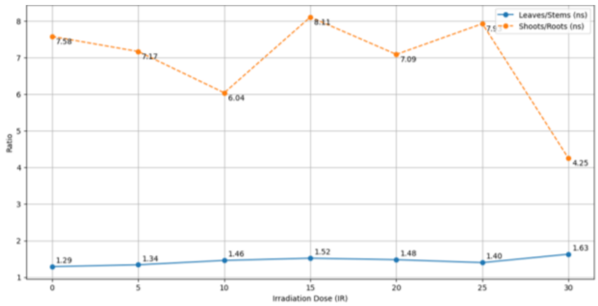

Fig. 6: The effect of irradiation dose on the fresh weight ratio of leaves/stems and shoots/roots of *Pennisetum purpureum* cv. Mot

Characteristics of Root Morphology of Pennisetum purpureum Cv Mot Generation M1 in Marginal Land

As illustrated in (Fig. 5) this study delves into the intricate relationship between gamma radiation and root morphology in *Pennisetum purpureum* cv Mot plants cultivated in marginal land conditions. The findings are compelling and illuminate the profound effects of varying radiation doses on root development.

The research outcomes are unequivocal- higher doses of gamma radiation precipitate a substantial reduction in root morphology characteristics, including root length, the number of roots, and root weight. Among these parameters, root weight exhibits the most pronounced decline, with the treatment of 30 Gy of radiation resulting in the lowest recorded root weight. Importantly, this outcome is significantly different from the control group, underscoring the considerable influence of gamma irradiation on root development.

These results corroborate the findings of a previous study conducted by Lee *et al*. (2019), which demonstrated that gamma radiation exerts inhibitory effects on the development of ginseng plant roots. The consistency between these studies reinforces the notion that gamma radiation has a potent inhibitory impact on plant root systems, transcending species-specific boundaries

An intriguing observation from this study is the correlation between irradiation dose and the extent of the inhibitory effect on root development. As the dose of irradiation increases, the strength of the inhibitory effect on root growth intensifies. This dose-response relationship accentuates the pivotal role played by external stressors, such as gamma radiation, in shaping root morphology.

Understanding the mechanistic underpinnings of how gamma radiation influences root development systems is essential. While this study sheds light on the observed correlations, further investigations into the genetic and molecular aspects are warranted. Identifying the specific genes, pathways, or regulatory mechanisms involved in radiation-induced root inhibition can provide deeper insights into the adaptive responses of plants to environmental stressors. Such knowledge is pivotal for devising strategies to enhance the radiation tolerance of crops, especially in regions where radiation exposure remains a significant concern.

Figure 5 underscores the substantial impact of gamma radiation on the root morphology of *Pennisetum purpureum* cv Mot plants in marginal land conditions. The findings contribute to our understanding of how radiation stress affects root development, opening avenues for future research into the genetic and molecular mechanisms involved. Ultimately, these insights are invaluable for the development of crop varieties that exhibit enhanced radiation resilience, thereby addressing critical agricultural challenges in radiation-prone regions.

The Effect of Gamma Irradiation on the Leaf/Stem Ratio and Shoot/Root Ratio of Pennisetum purpureum Cv. Mot Generation M1 in Marginal Land

Figure 6 provides a comprehensive view of the effects of gamma irradiation on *Pennisetum purpureum* cv. Mot Generation M1 plants cultivated in marginal land. The study's focus on the leaf/stem ratio and shoot/root ratio yields intriguing insights into the adaptive responses of these plants to ionizing radiation.

Surprisingly, statistical analyses reveal that gamma irradiation does not exert a significant effect on the leaf/stem ratio or the shoot/root ratio of these plants. The p-value ($p>0.05$) suggests that there is no substantial difference in the proportion of leaves to stems or shoots to roots between the irradiated group and the control group. This seemingly stable leaf/stem and shoot/root ratio may indicate that, at an overall proportionate level, the plants maintain equilibrium in their structural composition despite radiation exposure.

However, the true significance of these findings emerges when we delve deeper into the realm of root and stem morphology. While the shoot/root and leaf/stem ratios remain relatively constant, gamma irradiation introduces discernible alterations in the physical characteristics of both roots and stems. These changes could manifest in various ways, including alterations in shape, length, or size, all of which signify the plants' adaptations to radiation exposure.

The crux of these results underscores the intricate and multifaceted nature of plant responses to gamma radiation. Although the overall proportions of leaves, stems, shoots, and roots remain relatively stable, subtle yet significant shifts occur at the morphological level. These nuanced changes suggest that plants possess intricate adaptive mechanisms that enable them to uphold consistent growth rates and structural proportions while simultaneously undergoing specific morphological adjustments in response to radiation stress.

The implications of this study extend beyond the immediate context of radiation exposure. They underscore the remarkable adaptability of plants in challenging environments. By maintaining a relatively stable overall structure while adjusting specific morphological traits, plants exemplify their capacity to thrive in diverse ecological settings. Understanding these adaptive mechanisms is paramount not only for radiation ecology but also for broader ecological research, shedding light on how plants navigate and succeed in changing environments.

Figure 6 serves as a pivotal piece in unraveling the complexities of plant responses to gamma radiation. While the leaf/stem and shoot/root ratios remain stable, the alterations in root and stem morphology illuminate the plants' subtle yet significant adaptations. These findings underscore the resilience and adaptability of plants in the face of environmental stressors, offering valuable insights into the broader field of plant ecology and their ability to flourish amidst changing landscapes.

Table 1: Phenotypic variance (σ^2p), Genetic variance (σ^2g), Heritability (h^2), and Coefficient of Genetic Variation (CGV) for the characteristics of leaf count, leaf length, leaf width, plant height, and stem diameter

Irradiation dose	Parameters	σ^2g	σ^2p	h^2	CGV (%)	Criteria
5	Leaf count	18.86	27.63	0.68	19.76	Low
	Leaf length	13.32	23.33	0.57	43.07	Very high
	Leaf width	0.00	4.00	0.00	0.00	Low
	Plant height	14.12	23.19	0.61	15.87	Low
	Stem length	3.68	8.89	0.41	22.73	High
	Stem diameter	5.94	13.53	0.44	27.58	High
10	Leaf count	24.79	33.18	0.75	15.31	Low
	Leaf length	16.21	29.74	0.54	36.22	High
	Leaf width	0.00	4.00	0.00	0.00	Low
	Plant height	18.62	30.09	0.62	15.31	Low
	Stem length	2.16	5.00	0.43	20.00	High
	Stem diameter	4.14	9.09	0.46	25.20	High
15	Leaf count	27.55	38.55	0.71	14.12	Low
	Leaf length	15.51	29.03	0.53	38.19	High
	Leaf width	0.00	4.00	0.00	0.00	Low
	Plant height	18.78	29.89	0.63	14.27	Low
	Stem length	3.38	7.64	0.44	22.21	High
	Stem diameter	3.72	9.53	0.39	25.24	High
20	Leaf count	15.31	24.38	0.63	20.29	High
	Leaf length	11.64	19.74	0.59	43.44	Very high
	Leaf width	0.00	4.00	0.00	0.00	Low
	Plant height	19.69	30.00	0.66	14.88	Low
	Stem length	3.86	6.72	0.57	21.84	High
	Stem diameter	4.29	9.61	0.45	26.03	High
25	Leaf count	9.00	23.79	0.38	37.78	High
	Leaf length	5.52	18.88	0.29	46.65	Very high
	Leaf width	0.00	4.00	0.00	0.00	Low
	Plant height	13.78	28.79	0.48	17.85	Low
	Stem length	2.40	5.33	0.45	21.35	High
	Stem diameter	1.76	4.15	0.42	26.81	High
30	Leaf count	10.14	28.97	0.35	34.96	High
	Leaf length	6.52	22.44	0.29	40.90	Very high
	Leaf width	0.00	4.00	0.00	0.00	Low
	Plant height	12.48	26.78	0.47	17.52	High
	Stem length	2.09	5.00	0.42	20.95	High
	Stem diameter	1.21	3.16	0.38	25.76	High

The Influence of Gamma Radiation on the Morphological Diversity of Pennisetum purpureum Cv. Mot Generation M1 in Marginal Land

Understanding the influence of gamma radiation on the morphological characteristics of *Pennisetum purpureum* cv. Mot in marginal land is pivotal for comprehending the plant's adaptation mechanisms to ionizing radiation and its consequences on genetic diversity and heritability of these characteristics. In this study, we conducted a comprehensive examination of phenotypic variation, genetic diversity (σ^2g), heritability (h^2), and the Coefficient of Genetic Variation (CGV) pertaining to these morphological traits in response to varying gamma radiation levels, as summarized in Table 1.

Genetic diversity and heritability were leveraged to estimate the genetic advancements arising from selection (Ogunniyan and Olakojo, 2014). Furthermore, we explored the Heritability (h^2) of these morphological traits. Heritability offers insights into the degree to which genetic factors contribute to phenotypic variation (Visscher *et al*., 2008). Finally, the Coefficient of Genetic Variation (CGV) delineates the extent to which phenotypic variation in an observed trait is attributed to genetic factors in relation to environmental factors (Yadav *et al*., 2016

Within the framework of our research, a diverse array of morphological parameters in *Pennisetum purp*ureum cv. Mot plants subjected to varying doses of gamma radiation were meticulously measured. The analyses of Genetic variance (σ^2g), Phenotypic variance (σ^2p), Heritability (h^2), and the Coefficient of Genetic Variation (CGV) yield crucial insights into the genetic underpinnings of these plants in response to specific treatments.

Genetic variance (σ^2g): Genetic variance serves as a gauge of the extent to which genetic factors influence phenotypic variation in an observed trait. The analysis results highlight that σ^2g exhibits variations for each parameter and treatment. Lower values of σ^2g suggest that the observed phenotypic variation is more influenced by environmental factors than genetic factors, particularly notable in parameters such as leaf length and survival count. However, for select parameters like leaf weight and stem diameter, σ^2g tends to be relatively higher, underscoring the substantial influence of genetic factors on phenotypic variation in these traits.

Phenotypic variance (σ^2p): Phenotypic variance encapsulates the total observed variation in plant characteristics, encompassing contributions from both genetic and environmental factors. The analysis outcomes reveal that σ^2p also demonstrates variations across parameters and treatments. As the doses of gamma irradiation escalate, σ^2p tends to increase in certain parameters, including leaf length, stem diameter, and plant height. This suggests that phenotypic variation is not solely a product of genetic factors but is also influenced by environmental factors such as radiation dosage.

Heritability (h^2): Heritability quantifies the degree to which phenotypic variation in an observed trait can be attributed to genetic factors. The analysis results elucidate that h^2 varies across parameters and treatments. Lower h^2 values for parameters like leaf width indicate that phenotypic variation in these traits is more susceptible to environmental influences than genetic ones. Conversely, for parameters such as leaf length, stem diameter, and plant height, higher h^2 values suggest a more pronounced genetic contribution to the observed phenotypic variation.

Genetic Coefficient of Variation (CGV): CGV delineates the extent to which phenotypic variation in an observed trait is due to genetic factors, represented as a percentage. The analysis findings indicate that CGV also exhibits variations across parameters and treatments. Lower CGV values indicate that phenotypic variation in these parameters tends to be more influenced by environmental factors. In contrast, higher CGV values signify a substantial genetic contribution to the variation. For instance, in the case of leaf length, CGV reaches an impressive 44.59%, underscoring the significant genetic influence on phenotypic variation in this parameter.

CGV criteria: CGV criteria provide insights into the level of genetic influence on phenotypic variation. In this context, parameters like leaf length and stem diameter are categorized as "very high," signifying the pronounced influence of genetic factors on the observed phenotypic variation in these traits. Conversely, parameters like leaf width (L daun) exhibit a low CGV, indicating that environmental factors wield a more substantial impact on phenotypic variation in these parameters.

These meticulous analyses shed light on the pivotal role of genetic factors in shaping phenotypic variation in the characteristics of *Pennisetum purpureum* cv. Mot plants are particularly prominent in parameters such as leaf length and stem diameter. Nevertheless, it is essential to acknowledge the role of environmental factors, particularly the dosage of gamma irradiation, in comprehending the shifts in the morphological attributes of these plants.

The table indicates that the CGV (Coefficient of Genetic Determination) level of the observed characteristic can be used to measure the extent to which genetic factors influence the variation in that characteristic. The "high" and "very high" criteria indicate that genetic factors have a strong to very strong influence on the variation in the characteristic, with "Very High" indicating that genetic factors almost entirely dominate. Conversely, the "Low" criterion suggests that environmental factors play a greater role in the variation of that characteristic.

Conclusion

This study investigated the effects of gamma radiation on *Pennisetum purpureum* cv. Mot plants in marginal land. The results indicate that higher doses of gamma radiation lead to a decrease in leaf size, stem length, and root characteristics. We also identified the level of radiosensitivity in plants to gamma radiation, which can impact the selection of radiation-resistant varieties in agriculture. However, it is important to note that environmental factors, particularly the dose of gamma radiation, also play a role in phenotypic variation and radiosensitivity. This study highlights the complexity of the relationship between genetic factors, the environment, and plant responses to radiation. The findings of this research provide valuable insights into plant responses to gamma radiation and potential implications for selecting radiation-resistant plant varieties and understanding how plants respond to changing environments. Further research will delve deeper into the genetic factors influencing these responses and their applications in agriculture and plant biology research.

Acknowledgment

We extend our heartfelt thanks to the Directorate General of Higher Education, research, and Technology, Ministry of Education, culture, research, and Technology of the Republic of Indonesia for their generous support through the research funding for the year 2023. We are committed to making impactful contributions to science and our nation's progress through this collaboration. Furthermore, we express our sincere gratitude to the Dean of the faculty of agriculture and the rector of Muara Bungo University for their unwavering support and encouragement throughout this research journey. Their leadership and dedication to advancing scientific endeavors in our institution have been pivotal to our success. We also acknowledge the valuable contributions of our colleagues, advisors, and research assistants, who played a significant role in the study. Their expertise and support were invaluable throughout this research endeavor. Lastly, our heartfelt appreciation goes to the chairperson of Muara Bungo University's research and community service institute (LPPM) for their continuous support and guidance in our research endeavors.

Funding Information

The author would like to send gratitude to the directorate general of higher education, research, and technology, ministry of education, culture, research, and Technology of the Republic of Indonesia for their generous support through the research funding for the year 2023 under the research scheme number 186/E5/PG.02.00.PL/2023, which has been instrumental in our research efforts.

Author's Contributions

Bela Putra: The lead author of this study, who oversaw the entire research process, from data collection and analysis to manuscript preparation and ethical adherence.

Budi Prasetya: A co-author who offered critical feedback, assisted with data interpretation, and revised the manuscript.

Ethics

This research adhered to high ethical standards throughout the study, including the irradiation process using gamma rays and the plant experiments. The irradiation procedure was conducted in strict accordance with safety protocols and regulations to ensure the well-being of both researchers and the environment. All necessary permits and approvals were obtained for the safe handling and use of gamma radiation in compliance with national and international regulations governing radiation safety. Furthermore, the plant experiments were conducted with great care and consideration for the well-being of the plant specimens involved. Proper cultivation methods were employed and the plants were treated with respect and in accordance with ethical guidelines for research involving living organisms. Any potential impact on the plants' health and growth due to the experimental procedures was minimized and the research was carried out with the utmost dedication to the responsible treatment of plant specimens. Additionally, informed consent was obtained from any individuals who participated in this study and their identities were kept confidential. Data privacy and protection measures were in place to ensure the security of all personal information and research data, including data related to irradiation experiments and plant growth. The research methodology and data handling procedures were carried out with transparency and all data sources and references have been appropriately cited in this research article. The authors are committed to upholding the principles of scientific integrity, honesty, and transparency in all aspects of research and reporting, particularly in the context of irradiation experiments and plant experiments. Any conflicts of interest or potential biases have been disclosed. We aim to contribute responsibly to the scientific community and promote the ethical conduct of research, including the safe and responsible use of gamma radiation, in our field.

References

Abdullah, T. L., Johari, E., & Mohd, N. (2009). Changes in flower development, chlorophyll mutation and alteration in plant morphology of curcuma alismatifolia by gamma irradiation. *American Journal of Applied Sciences*, *6*(7), 1436-1439. https://www.cabdirect.org/cabdirect/abstract/20093253537

Aisyah, S. I., Aswidinnoor, H., Saefuddin, A., Marwoto, B., & Sastrosumarjo, S. (2009). Induksi mutasi pada stek pucuk anyelir (*Dianthus caryophyllus* Linn.) melalui iradiasi sinar gamma. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, *37*(1). https://journal.ipb.ac.id/index.php/jurnalagronomi/article/view/1396

Ambavane, A. R., Sawardekar, S. V., Sawantdesai, S. A., & Gokhale, N. B. (2015). Studies on mutagenic effectiveness and efficiency of gamma rays and its effect on quantitative traits in finger millet (*Eleusine coracana* L. Gaertn). *Journal of Radiation Research and Applied Sciences*, *8*(1), 120-125. https://doi.org/10.1016/j.jrras.2014.12.004

Ananta, D., Bachruddin, Z., & Umami, N. (2019). Growth and production of 2 cultivars (*Pennisetum purpureum* Schumach.) on regrowth phase. *In IOP Conference Series: Earth and Environmental Science 387*(1), 012033. IOP Publishing. https://doi.org/10.1088/1755-1315/387/1/012033

Chouychai, W., & Somtrakoon, K. (2022). Potential of plant growth regulators to enhance arsenic phytostabilization by *Pennisetum purpureum* cv. Mott. *Pertanika Journal of Tropical Agricultural Science*, *45*(3), 835-851. https://doi.org/10.47836/pjtas.45.3.18

Fallah, A. A., Sarmast, E., Dehkordi, S. H., Isvand, A., Dini, H., Jafari, T., ... & Khaneghah, A. M. (2022). Low-dose gamma irradiation and pectin biodegradable nanocomposite coating containing curcumin nanoparticles and ajowan (*Carum copticum*) essential oil nanoemulsion for storage of chilled lamb loins. *Meat Science*, *184*, 108700. https://doi.org/10.1016/j.meatsci.2021.108700

Harsanti, L., & Dewi, A. K. (2013). Perbaikan padi varietas cisantana dengan mutasi induksi. *Jurnal Ilmiah Aplikasi Isotop Dan Radiasi*, *5*(2). https://jurnal.batan.go.id/index.php/jair/article/view/534

Hemerly, A., Engler, J. D. A., Bergounioux, C., Van Montagu, M., Engler, G., Inzé, D., & Ferreira, P. (1995). Dominant negative mutants of the Cdc2 kinase uncouple cell division from iterative plant development. *The EMBO Journal*, *14*(16), 3925-3936. https://doi.org/10.1002/j.1460-2075.1995.tb00064.x

Hou, R., Yang, L., Wuyun, T., Chen, S., & Zhang, L. (2023). Genes related to osmoregulation and antioxidation play important roles in the response of Trollius chinensis seedlings to saline-alkali stress. *Frontiers in Plant Science*, *14*, 1080504. https://doi.org/10.3389/fpls.2023.1080504

Kalton, R. R., Smit, A. G., & Leffel, R. C. (1952). Parent-inbred progeny relationships of selected orchardgrass Clones 1. *Agronomy Journal*, *44*(9), 481-486. https://doi.org/10.2134/agronj1952.00021962004400090007x

Kowitwiwat, A., & Sampanpanish, P. (2020). Phytostabilization of arsenic and manganese in mine tailings using *Pennisetum purpureum* cv. Mott supplemented with cow manure and acacia wood-derived biochar. *Heliyon*, *6*(7). https://doi.org/10.1016/j.heliyon.2020.e04552

Lee, J. W., Jo, I. H., Kim, J. U., Hong, C. E., Bang, K. H., & Park, Y. D. (2019). Determination of mutagenic sensitivity to gamma rays in ginseng (*Panax ginseng*) dehiscent seeds, roots, and somatic embryos. *Horticulture, Environment, and Biotechnology*, *60*, 721-731. https://doi.org/10.1007/s13580-019-00164-2

Mulyani, A., & Hikmatullah, S. H. (2004). Karakteristik dan potensi tanah masam lahan kering di Indonesia. *Prosiding Simposium Nasional Pendugaan Tanah Masam. Bogor (Indones): Pusat Penelitian Dan Pengembangan Tanah Dan Agroklimat*, 1-32. http://scholar.unand.ac.id/121071/3/Daftar%20Pustaka.pdf

Mulyani, A., & Sarwani, M. (2013). Karakteristik dan potensi lahan sub optimal untuk pengembangan pertanian di Indonesia.

Ogunniyan, D. J., & Olakojo, S. A. (2014). Genetic variation, heritability, genetic advance and agronomic character association of yellow elite inbred lines of maize (*Zea mays* L.). *Nigerian Journal of Genetics*, *28*(2), 24-28. https://doi.org/10.1016/j.nigjg.2015.06.005

Owis, A. I., Sherif, N. H., Hassan, A. A., El-Naggar, E. M. B., El-Khashab, I. H., & El-Ghaly, E. S. (2023). Tropaeolum majus L and low dose gamma radiation suppress liver carcinoma development via EGFR-HER2 signaling pathway. *Natural Product Research*, *37*(6), 1030-1035. https://doi.org/10.1080/14786419.2022.2098958

Pongtongkam, P., Peyachoknagul, S., Arananant, J., Thongpan, A., & Tudsri, S. (2006). Production of salt tolerance dwarf napier grass (*Pennisetum purpureum* cv. Mott) using tissue culture and gamma irradiation. *Agriculture and Natural Resources*, *40*(3), 625-633. https://li01.tcithaijo.org/index.php/anres/article/view/243714

Putra, B., Warly, L., Evitayani, E., & Utama, B. P. (2022). The role of arbuscular mycorrhizal fungi in phytoremediation of heavy metals and their effect on the growth of *Pennisetum purpureum* cv. Mott on gold mine tailings in muara bungo, jambi, Indonesia. *Biodiversitas Journal of Biological Diversity*, *23*(1). https://doi.org/10.13057/biodiv/d230151

Shu, Q. Y., Forster, B. P., & Nakagawa, H. (Eds.). (2012). *Plant mutation breeding and biotechnology*. Cabi. https://www.cabidigitallibrary.org/doi/abs/10.1079/9781780640853.0000

Singh, S. K., Borthakur, D., Tamuly, A., Manjaya, J. G., Patel, P. K., Gogoi, B., ... & Barooah, A. K. (2023). Assessment of gamma radiation through agro-morphological characters in camellia sinensis L.(O.) kuntze. *International Journal of Radiation Biology*, *99*(5), 866-874. https://doi.org/10.1080/09553002.2022.2121872

Su, X. A., Dion, V., Gasser, S. M., & Freudenreich, C. H. (2015). Regulation of recombination at yeast nuclear pores controls repair and triplet repeat stability. *Genes and Development*, *29*(10), 1006-1017. https://doi.org/10.1101/gad.256404.114

Syukur, M., Sujiprihati, S., Yunianti, R., & Kusumah, D. A. (2011). Pendugaan ragam genetik dan heritabilitas karakter komponen hasil beberapa genotipe cabai. http://repository.ipb.ac.id/handle/123456789/58433

Tamboli, P., Chaurasiya, A. K., Upadhyay, D., & Kumar, A. (2023). Climate change impact on forage characteristics: An appraisal for livestock production. *In Molecular Interventions for Developing Climate-Smart Crops: A Forage Perspective* 183-196. Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-1858-4_10

Utomo, R., Agus, A., Noviandi, C. T., Astuti, A., & Alimon, A. R. (2021). *Bahan Pakan Dan Formulasi Ransum*. UGM PRESS. ISBN-10: 6023869351.

Visscher, P. M., Hill, W. G., & Wray, N. R. (2008). Heritability in the genomics era-concepts and misconceptions. *Nature Reviews Genetics*, *9*(4), 255-266. https://doi.org/10.1038/nrg2322

Widoretno, W., Rohmah, M., & Indriyani, S. (2023). Effect of gamma-ray irradiation on vetiver grass (*vetiveria zizanioides* (L.) Nash.) *in vitro* shoots growth and multiplication. *In 3rd International Conference on Biology, Science and Education (IcoBioSE 2021)* 181-190. Atlantis Press. https://doi.org/10.2991/978-94-6463-166-1_26

Wu, Z. L., Yang, X., Zhang, J., Wang, W., Liu, D., Hou, B., ... & Xia, Y. (2023). Effects of forage type on the rumen microbiota, growth performance, carcass traits and meat quality in fattening goats. *Frontiers in Veterinary Science*, *10*, 1147685. https://doi.org/10.3389/fvets.2023.1147685

Yadav, A., Dhole, K., & Sinha, H. (2016). Differential regulation of cryptic genetic variation shapes the genetic interactome underlying complex traits. *Genome Biology and Evolution*, *8*(12), 3559-3573. https://doi.org/10.1093/gbe/evw258

Yali, W., & Mitiku, T. (2022). Mutation breeding and its importance in modern plant breeding. *Journal of Plant Sciences*, *10*(2), 64-70. https://doi.org/10.11648/j.jps.20221002.13

Yulia, N., Prihantoro, I., & Karti, P. D. M. H. (2022). Optimasi penggunaan mutagen kolkisin untuk peningkatan produktivitas tanaman stylo (*Stylosanthes guianensis* (Aubl.) Sw.). *Jurnal Ilmu Nutrisi Dan Teknologi Pakan (Nutrition and Feed Technology Journal)*, *20*(1), 19-24. https://doi.org/10.29244/jintp.20.1.19-24