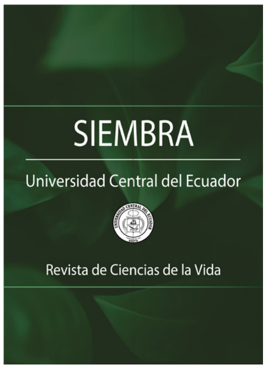
Effect of gamma ray on the morphology of two in vitro taro cultivars (Colocasia esculenta L. Schott)

Efecto de la irradiación con rayos gamma sobre la morfología de dos cultivares in vitro de malanga (Colocasia esculenta L. Schott)



Heeidy Guadalupe Corea Narváez[1], Rosario del Socorro García Loáisiga[2], Guillermo del Carmen Reyes Castro[3], Yosmara Belén Martínez Martínez[4], Yarin José Briones Ramírez[5]

Siembra 12 (1) (2025): e7438

Received: 05/11/2024 / Reviewed: 18/12/2024/ Accepted: 24/02/2025

[1] Universidad Nacional Agraria, Dirección de Ciencias Agrarias. Kilómetro 12.5 carretera Norte. CP 453. Managua, Nicaragua.
✉ heidycorea12@gmail.com
https://orcid.org/0000-0002-1095-8218

[2] Profesional independiente. Managua, Nicaragua.
✉ rosariocomp@yahoo.com
https://orcid.org/0000-0002-4433-9917

[3] Universidad Nacional Agraria. Carazo, Nicaragua.
✉ memoreyes0309@gmail.com
https://orcid.org/0000-0003-0164-437X

[4] Profesional independiente. Managua, Nicaragua.
✉ martinezbelen1697@gmail.com
https://orcid.org/0009-0000-5965-6221

[5] Profesional independiente. Managua, Nicaragua.
✉ jaringbriones1@gmail.com
https://orcid.org/0009-0004-4195-9039

** Corresponding author:*
heidycorea12@gmail.com

SIEMBRA
https://revistadigital.uce.edu.ec/index.php/SIEMBRA
ISSN-e: 2477-5788
Frequency: half-yearly
vol. 12, issue 1, 2025
siembra.fag@uce.edu.ec
DOI: https://doi.org/10.29166/siembra.v12i1.7438

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Abstract

In Nicaragua, two taro cultivars (Lila and Blanca) (*Colocasia esculenta* L. Schott) are cultivated, yet neither cultivar exhibits tolerance to biotic or abiotic factors. The crop requires abundant water, and in Nicaragua the rainy season is insufficient to meet water requirements for this crop. Gamma radiation has been identified as a tool to accelerate plant breeding programs. The present study evaluated the effect of gamma ray irradiation as a source of mutation induction in the morphology of two taro cultivars. *In vitro* plants of Lila and Blanca taro were irradiated with 0 (control), 5, 10, 15, 20, 25 and 30 Gy of gamma rays. The variables evaluated were plant height (cm), leaf number, shoot number, root number, survival percentage, 50% growth reduction dose [GR_{50}] and 50% lethal dose [LD_{50}]. In both cultivars the variables presented a negative correlation with the irradiation doses; as the doses increased, plant height, number of leaves, shoots and roots decreased. The optimal irradiation doses for Lila taro were determined to be 10, 13 and 16 Gy, while for Blanca taro these doses were 20, 25 and 30 Gy. In the case of Blanca taro, 100% survival was recorded in the control and at the 5 and 10 Gy doses. In the case of Lila taro, 100% survival was recorded in the control and at the 5 Gy dose. The LD_{50} in Lila taro was determined to be 19 Gy, while in Blanca taro, the LD_{50} was established as 53 Gy.

Keywords: radiosensitivity test, mutation induction, mutational improvement, physic mutagenesis.

Resumen

En Nicaragua se siembran dos cultivares de malanga (Lila y Blanca) (*Colocasia esculenta* L. Schott) ninguno tolerante a factores bióticos o abióticos. El cultivo requiere agua abundante y en Nicaragua la época lluviosa no es suficiente para cumplir con las necesidades hídricas (1.800-2.500 mm año^{-1}). Las radiaciones gamma constituyen una herramienta para acelerar los programas de mejoramiento genético. En este estudio se evaluó el efecto de la irradiación con rayos gamma, como fuente de inducción de mutaciones en la exomorfología de dos cultivares de malanga. Plantas *in vitro* de malanga Lila y Blanca se irradiaron con 0 (testigo), 5, 10, 15, 20, 25 y 30 Gy de rayos gamma. Se evaluó altura de planta (cm), número de hojas, número de brotes, número de raíces, porcentaje de sobrevivencia, dosis de reducción de crecimiento en 50% [DR_{50}] y dosis letal 50% [DL_{50}]. En ambos cultivares las variables mostraron una correlación negativa con las dosis de irradiación; a medida que las dosis aumentaron, la altura de planta, el número de hojas, brotes y raíces disminuyó. La dosis de irradiación óptima en malanga Lila fueron 10, 13 y 16 Gy, en malanga Blanca fueron 20, 25 y 30 Gy. El 100% de sobrevivencia en malanga Blanca se registró en el testigo y las dosis 5 y 10 Gy; y en malanga Lila en el testigo y la dosis 5 Gy. La DL_{50} en malanga Lila fue de 19 Gy y en malanga Blanca la DL_{50} fue de 53 Gy.

Palabras clave: prueba de radiosensibilidad, inducción de mutaciones, mejora mutacional, mutagénesis física.

1. Introduction

Taro (*Colocasia esculenta* L. Schott) is a member of the Araceae family and originates from Southeast Asia, between India and Indonesia (López Zada et al., 1984). In Nicaragua, two taro cultivars are grown (Lila and Blanca). The Lila cultivar, also known as *malanga Coco*, has the highest production due to its export potential, high yield capacity, and domestic consumption. Neither cultivar is tolerant to biotic or abiotic factors (Enríquez Juárez & Mairena Úbeda, 2011).

The phenological cycle of taro ranges between seven and nine months, during which it requires abundant water (between 1,800 and 2,500 mm $year^{-1}$) (López Zada et al., 1984). In Nicaragua, the rainy season lasts about six months and is sometimes insufficient to meet the crop's water requirements. Nicaragua is vulnerable to droughts, affecting nearly 45% of the national population (Ramírez et al., 2010). Therefore, it is necessary to develop drought-tolerant cultivars to ensure agricultural production under the country's adverse conditions.

Taro has unisexual flowers: pistillate flowers at the base of the spadix and staminate flowers at the tip, with a group of sterile flowers between both zones. This irregular pollination process makes seed production infrequent (López Zada et al., 1984; Lozada Barrera, 2005), making hybridization or crossbreeding for improvement difficult. To generate genetic variation, gamma rays—physical mutagens—are used, as they have proven useful in producing new trait variants that can lead to crop improvement (Babaei, 2010; Antúnez-Ocampo et al., 2017).

The application of gamma radiation combined with tissue culture in taro is a tool to accelerate genetic improvement programs (Martirena-Ramírez et al., 2018), achieving viable mutations at high frequency in many cultivars of different species (Ilyas & Naz, 2014).

To carry out a mutation breeding program, it is essential to begin by identifying the appropriate mutagenic treatment. This involves determining the radiosensitivity and the dose that causes a 50% reduction in vegetative growth, which is estimated through the physiological response of the irradiated material (Sarsu et al., 2021a).

In Nicaragua, no studies have been conducted on taro regarding gamma-ray-induced mutations. Therefore, this study evaluated the effect of gamma irradiation as a source of mutation induction on the exomorphology of two taro cultivars (Lila and Blanca), in order to determine the optimal irradiation dose for each cultivar and subsequently perform mass irradiation to obtain a promising mutant tolerant to water stress.

2. Materials and Methods

2.1. Study area

In vitro plants of the Lila and Blanca taro cultivars were established at Laboratorio de Cultivo de Tejidos Vegetales [LCTV] of the Universidad Nacional Agraria [UNA], in Managua, Nicaragua, located at coordinates 12°08'58.3" N latitude and 86°09'37.0" W longitude. The plants were then transferred to Cuba to undergo gamma irradiation.

The preparation of the explants was carried out at the tissue culture laboratory of the Instituto de Investigación en Viandas Tropicales [INIVIT] in Santo Domingo, Cuba, located at 22°35'08.2" N latitude and 80°13'35.2" W longitude. The gamma irradiation of the explants was conducted at the Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear [CEADEN] in Havana, Cuba, located at 23°07'08.9" N latitude and 82°25'28.5" W longitude. The irradiated explants were then returned to the LCTV at UNA for evaluation.

2.2. Research design

A completely randomized design [CRD] was established, with two factors: irradiation dose and cultivar, including seven treatments and thirty observations per treatment. The treatments studied were gamma irradiation doses of 0 (control), 5, 10, 15, 20, 25, and 30 Gray [Gy]).

2.3. Preparation of plant material

In the tissue culture laboratory of INIVIT, the in vitro plants were dissected to obtain meristematic apices. Five meristematic apices were placed in 5 ml Eppendorf tubes containing liquid MS culture medium, with four replicates per dose.

An Isogamma LLCo irradiator with a Cobalt-60 source and a dose rate of 0.006×Gy h^{-1} was used at CEADEN to irradiate the explants. The control and doses of 5, 10, 15, 20, 25, and 30 Gy were applied to both cultivars.

After irradiation, the explants were transferred to the INIVIT laboratory and cultured in plastic flasks containing multiplication medium (Murashige and Skoog [MS] at 80%, supplemented with 100 mg l^{-1} of inositol, 0.1 mg l^{-1} of 6-Benzylaminopurine, 10 mg l^{-1} of MS vitamins, and 0.05 mg l^{-1} of indole-3-acetic acid). They were placed in an incubation room with light intensity of 3,000–5,000 lux for six days.

Thirty days after irradiation [DAI], the explants were transferred, without cuts, to multiplication medium at the LCTV of UNA.

2.4. Assessed variables

The following morphological variables were assessed at 69 DAI:

- Plant height (cm): Plant height was measured using sterile graph paper, from the base of the pseudostem to the point where the petiole is inserted, using the tallest leaf on the plant as reference.
- Leaf number (unit): The total number of leaves per plant was counted.
- Shoot number (unit): The total number of shoots per plant was counted.
- Root number (unit): The total number of roots per plant was counted.
- Survival rate (%): The total number of explants that survived each irradiation dose was recorded, and the percentage was calculated.
- Growth reduction dose (GR_{50}): Plant height and Shoot number were used, as these variables had the highest coefficients of determination (R^2). For each variable, the percentage of growth was calculated by comparing each dose to the control treatment (0 Gy), and the dose that reduced growth by 50% was determined.
- Lethal dose for 50% of the population (LD_{50}): The number of surviving plants was recorded, and the dose that reduced the population by 50% was calculated.

To determine GR_{50} and LD_{50}, a linear regression analysis was performed.

3. Results and Discussion

3.1. Linear regression analysis of the morphological variables of the Lila taro cultivar

Figure 1 shows the trend graphs, linear regression equations, and coefficients of determination (R^2) for each morphological variable evaluated in the Lila taro cultivar. For the variables assessed, the fitted curve based on the linear equation showed a negative correlation between each variable and the irradiation doses. As the doses increased, plant height, number of leaves, shoots, and roots decreased.

The R^2 value for each variable was considered: plant height (0.7811), leaf number (0.4231), shoot number (0.8956), and root number (0.6978). Plant height and shoot number were selected to calculate the GR_{50}, as they showed the highest coefficients of determination, indicating a better fit (Figure 1).

The selection of variables that contribute to determining an optimal dose must be made carefully, considering the physiological conditions of the plant. Plant height is recommended by some authors (Sarsu et al., 2021a, Pérez Ponce, 1998); shoot number indicates the propagation potential of the plants in the *in vitro* stage, which is essential for multiplying the plant in later stages and for separating chimeras resulting from mutation induction.

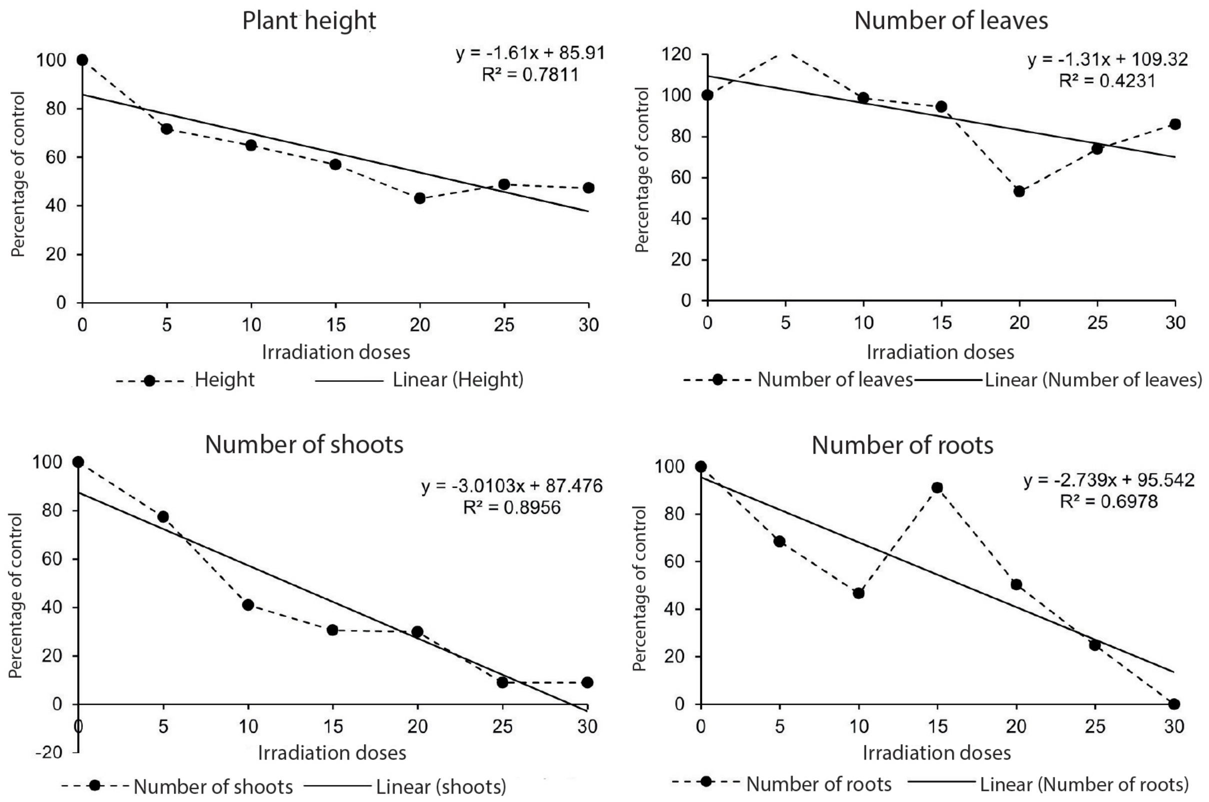


Figure 1. Linear regression analysis of the irradiation dose and its effect on the measured variables: plant height, number of leaves, number of shoots and number of roots, of in vitro plants of Lila taro irradiated with gamma rays.

One factor that affects mutant formation is the irradiation dose to which the explants are exposed (Nurilmala et al., 2017). The dose rate often has significant effects, both qualitative and quantitative, on the results obtained. For this reason, the dose rate must be carefully selected (Spencer-Lopes et al., 2021) to determine an optimal dose capable of inducing mutations without impairing the productive qualities of the cultivars.

The dose required to induce mutations depends on the desired effects. Higher doses cause more drastic mutations such as chromosomal aberrations and can damage the apical meristem, which is why lower doses are generally preferred (Sarsu et al., 2021a).

3.2. Linear regression analysis of the morphological variables of the Blanca taro cultivar

Figure 2 presents the trend graphs, linear regression equations, and R^2 values for each morphological variable evaluated in the Blanca taro cultivar. For the variables assessed, the fitted curve based on the linear equation showed a negative correlation between each variable and the irradiation doses. As the doses increased, a decrease was observed in plant height and in the number of leaves, shoots, and roots.

The coefficient of determination (R^2) was considered for each variable: plant height (0.8326), leaf number (0.7515), shoot number (0.7602), and root number (0.7701). To calculate the GR_{50}, plant height and number of shoots were selected (Figure 2).

Asexually reproducing species, such as taro, can be induced to mutate through exposure of somatic tissue to ionizing radiation, which may cause changes in the genetic material of irradiated cells (Robles Sánchez, 1986).

The number of mutant plants that carry only desirable changes decreases if more than one mutation is induced per cell. To avoid this, several measures can be taken, one of which is to avoid applying excessively high doses of any mutagen (Mukhtar Ali Ghanim et al., 2021).

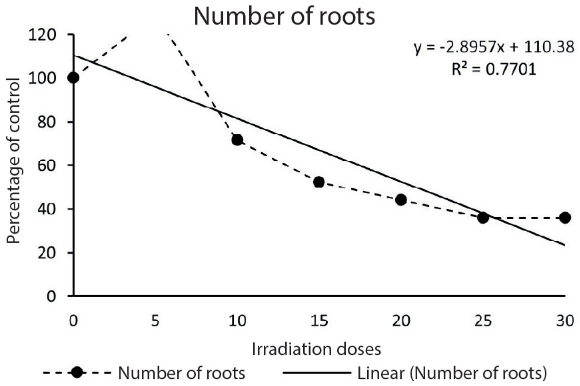


Figure 2. Linear regression analysis of the irradiation dose and its effect on the measured variables: plant height, number of leaves, number of shoots and number of roots of in vitro plants of Blanca taro irradiated with gamma rays.

3.3. Growth reduction dose (GR_{50}) for the variables plant height and number of shoots in Lila taro

The irradiation doses for the Lila taro cultivar were calculated by averaging the GR_{50} values of plant height (17.5 Gy) and shoot number (8.8 Gy), resulting in an optimal dose of 13.15 Gy. According to some authors (Mukhtar Ali Ghanim et al., 2021; Spencer-Lopes et al., 2021), it is advisable to use three irradiation doses, which should be ±20% of the optimal dose. For Lila taro, the resulting irradiation doses were: 10.50 (10 Gy), 13.15 (13 Gy), and 15.78 (16 Gy) (Figure).

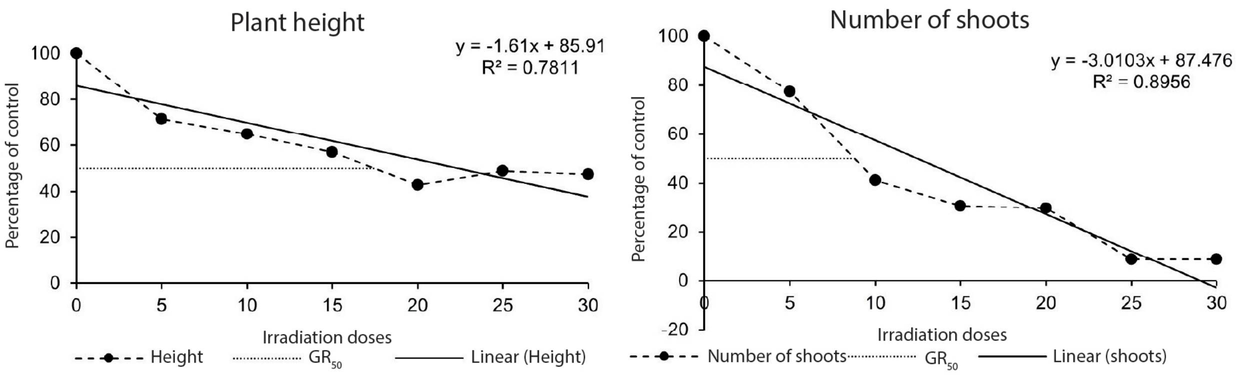


Figure 3. Regression analysis and 50% reduction dose of plant height and shoot number of in vitro plants of Lila taro irradiated with gamma rays.

The determination of radiosensitivity and the dose that causes a 50% reduction in vegetative growth [GR_{50}] must be carried out to estimate the most appropriate mutagenic treatment. This is generally estimated based on the physiological response of the irradiated material (Sarsu et al., 2021b). Based on the radiosensitivity test, it was determined that the gamma ray treatments that reduced plant height and shoot number by 50% in the Lila taro cultivar were 17.5 Gy and 8.8 Gy, respectively.

Other studies have shown that a 30% reduction in leaf number in taro occurred with a dose of 7.65 Gy (Seetohul et al., 2008). The ability to induce desirable mutations in taro using gamma rays has been achieved with a dose of 10 Gy (Vasudevan & Jos, 1990). A dose of 10 Gy has been found to be effective for increasing leaf number, while doses between 15 and 20 Gy have a strong darkening effect on taro explants and inhibit growth, with some explants dying after the third week (Nurilmala et al., 2017). Gamma irradiation using a Co60 source has been shown to increase phenotypic variability in mutant populations (Sahoo et al., 2015).

3.4. Growth reduction dose (GR_{50}) for the Variables plant height and shoot number in Blanca taro

The irradiation doses for the Blanca taro cultivar were calculated by averaging the GR_{50} values of plant height (32 Gy) and shoot number (17 Gy), resulting in an optimal dose of 24.5 Gy. The optimal irradiation doses calculated using ±20% of this value were 19.6 (20 Gy), 24.5 (25 Gy), and 29.4 (30 Gy) (Figure 4).

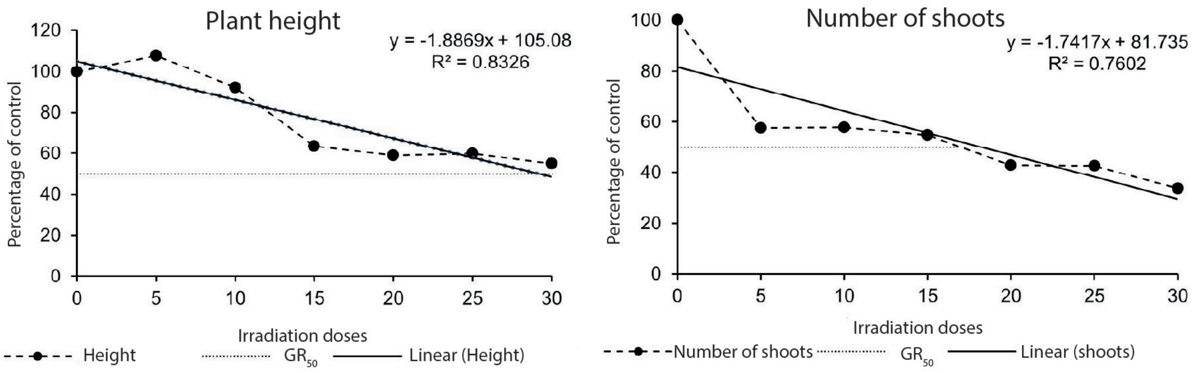


Figure 4. Regression analysis and 50% reduction dose of plant height and number of shoots of in vitro plants of Blanca taro irradiated with gamma rays.

In species such as *Agave fourcroydes* and *Agave tequilana*, the reduction dose was 20 and 25 Gy for fresh callus weight, plant height, and induction of adventitious shoots (Ángeles-Espino et al., 2013; González Oramas et al., 2007).

The results obtained for the Lila and Blanca taro cultivars were like those reported for *Chrysanthemum morifolium, Lealia autumnalis*, and *Saccharum officinarum* (Hernández-Muñoz et al., 2017; Latado, 1993; Otahola Gómez et al., 2001; Valdez Balero et al., 2004), where irradiation doses between 10 and 30 Gy reduced explant growth by 50%, showing significant differences compared to the control. This behavior may be related to the physiological and cytological effects that irradiation produces in cells, as noted by some authors (García Rodríguez et al., 2000).

There is a strong correlation between genotypes and the sensitivity of plant material to mutagenic treatments. Higher doses cause more drastic mutations, such as chromosomal aberrations, and can damage the apical meristem, which is why lower doses are generally preferred. Preliminary trials are recommended to determine the appropriate doses for each plant material (Sarsu et al., 2021a). In this study, the irradiation doses obtained for Lila taro did not exceed 16 Gy, and for Blanca taro did not exceed 30 Gy, both considered low doses.

3.5. survival percentage in the Blanca and Lila taro cultivars

In Blanca taro, the highest survival percentage was recorded in control and in the 5 and 10 Gy treatments, all with 100%, and the lowest was at 30 Gy with 72.42%. In Lila taro, the control and 5 Gy treatments also showed the highest survival percentage (100%), while the lowest was at 30 Gy, with 13.33% (Figure 5).

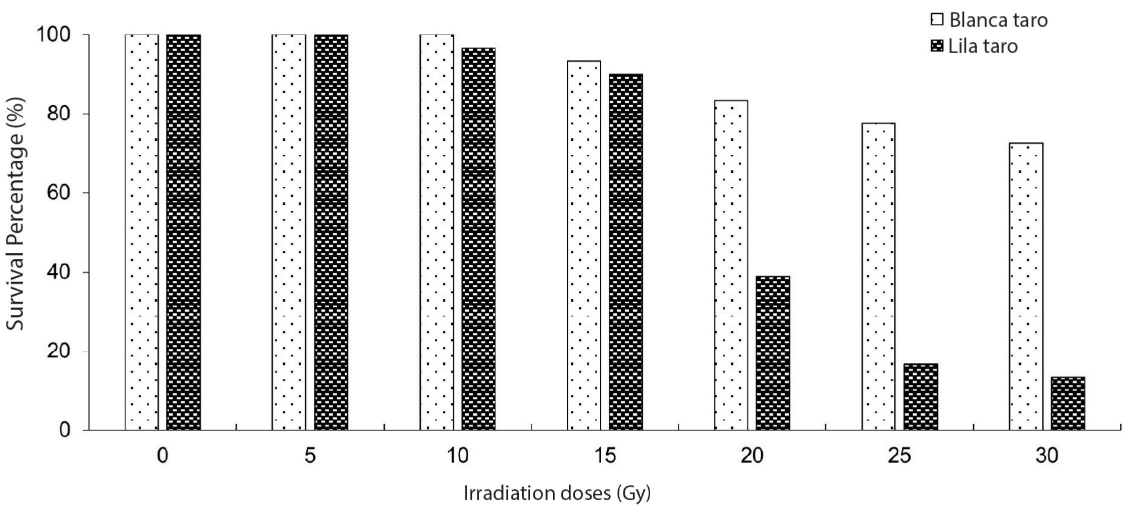


Figure 5. Effect of gamma irradiation on the survival of Blanca and Lila taro, evaluated after 69 days of irradiation.

Radiosensitivity can vary depending on the species, cultivar, and genotype, as well as the physiological conditions of the plants, the specific organs involved, and the types of mutagenic treatments used (Sarsu et al., 2021b). This explains why the Lila taro cultivar shows a lower survival rate at doses above 20 Gy compared to the Blanca cultivar, indicating greater susceptibility to higher doses. In other studies, doses above 20 Gy were lethal for *in vitro* taro explants (Seetohul et al., 2008).

3.6. Lethal Dose 50% (LD_{50}) in the Lila and Blanca taro cultivars

The LD_{50} for the Lila taro cultivar was 19 Gy, and doses of 25 and 30 Gy caused mortality rates of 83.33% to 86.67% of irradiated explants (Figure 6). None of the irradiation doses used in this study resulted in 50% mortality in the Blanca taro explants. However, using the simple linear regression equation, the LD_{50} for Blanca taro was estimated to be 53 Gy.

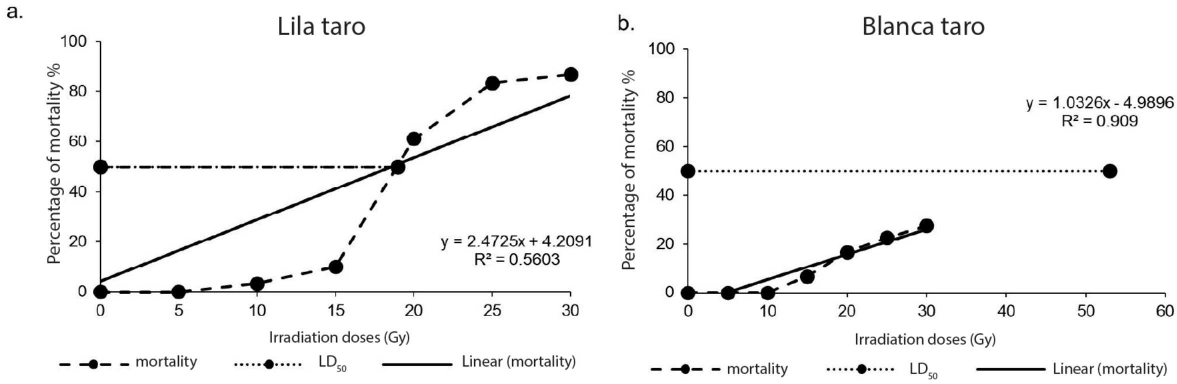


Figure 6. Lethal dose of in vitro plants irradiated with gamma rays: a. Lila taro and b. Blanca taro.

The LD_{50} corresponds to the amount of absorbed radiation at which 50% of the exposed population survives. This proportion is considered the range in which the appearance of useful mutations is favored in plant breeding programs (Fuchs et al., 2002).

Similar results have been obtained in other studies on taro, with an LD_{50} of 20 Gy of gamma rays (Medero Vega et al., 2014); in *Polianthes tuberosa* L., an LD_{50} of 25.91 Gy was determined (Estrada Basaldúa et al., 2011); in the potato cultivar 'Desirée, it was 10 Gy (Veitía et al., 2007); and in *Laelia autumnalis* explants, it was 53 Gy (Hernández-Muñoz et al., 2017).

The LD_{50} values for Lila and Blanca taro differed because not all genotypes exhibit the same radiosensitivity to ionizing radiation and mutagenic agents. It has been shown that different types of explants (such as seeds or vegetative parts like buds or apices) respond differently to the same mutagenic treatment (Medero Vega et al. 2014). As a result, the selected irradiation doses for Lila and Blanca taro were different: 13 Gy for Lila and 25 Gy for Blanca.

4. Conclusions

Gamma irradiation affected the morphology of both Lila and Blanca taro cultivars. As the dose increased, plant height, number of leaves, shoots, and roots decreased.
The optimal irradiation doses were higher for Blanca taro (20, 25, and 30 Gy) than for Lila taro (10, 13, and 16 Gy).

Contributor roles

- Heeidy Guadalupe Corea Narváez: conceptualization, formal analysis, investigation, methodology, writing – original draft.
- Rosario del Socorro García Loáisiga: conceptualization, formal analysis, investigation, methodology.

- Guillermo del Carmen Reyes Castro: conceptualization, funding acquisition, project administration, resources, supervision.
- Yosmara Belén Martínez Martínez: investigation, methodology.
- Yarin José Briones Ramírez: investigation, methodology.

Ethical implications

Ethics approval not applicable.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

Referencias

Ángeles-Espino, A., Valencia-Botín, A. J., Virgen-Calleros, G., Ramírez-Serrano, C., Paredes-Gutiérrez, L., & Hurtado-De la Peña, S. (2013). Determinación de la dosis letal (DL_{50}) con Co^{60} en vitroplántulas de *Agave tequilana* var. Azul. *Fitotecnia Mexicana*, 36(4), 381-386. https://revistafitotecniamexicana.org/documentos/36-4/2a.pdf

Antúnez-Ocampo, O. M., Cruz-Izquierdo, S., Sandoval-Villa, M., Santacruz-Varela, A., Mendoza-Onofre, L. E., de la Cruz-Torres, E., & Peña-Lomelí, A. (2017). Variabilidad inducida en caracteres fisiológicos de *Physalis peruviana* L. mediante rayos gamma ^{60}Co aplicados a la semilla. *Revista Fitotecnia Mexicana*, *40*(2), 211-218. https://doi.org/10.35196/rfm.2017.2.211-218

Babaei, A. (2010). Genetic Diversity Analysis of Nemat Rice Mutant (*Oryza sativa* L.) Via RAPD Marker. *American-Eurasian Journal of Agricultural & Environmental Sciences*, *8*(4), 452-456. https://idosi.org/aejaes/aejaes8(4).htm

Enríquez Juárez, D. Y., & Mairena Úbeda, E. N. (2011). *Efecto de dos condiciones de humedad del suelo y tiempo de cosecha sobre el rendimiento de malanga (Colocasia esculenta L. Schott) para exportación Boaco - Nicaragua 2011*. Universidad Nacional Agraria. https://repositorio.una.edu.ni/id/eprint/2140

Estrada Basaldúa, J. A., Pedraza Santos, M. E., De la Cruz Torres, E., Martínez Palacios, A., Sáenz Romero, C., & Morales García, J. L. (2011). Efecto de rayos gamma ^{60}CO en nardo (*Polianthes Tuberosa* L.). *Revista Mexicana de Ciencias Agrícolas*, *2*(spe3), 445-458. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-09342011000900004&lng=es&tlng=es

Fuchs, M., González, V., Castroni, S., Díaz, E., & Castro, L. (2002). Efecto de la radiación gamma sobre la diferenciación de plantas de caña de azúcar a partir de callos. *Agronomía Tropical*, *52*(3), 311-324. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0002-192X2002000300004&lng=es&tlng=es

García Rodríguez, L., Bermúdez Caraballoso, I., Orellana Pérez, P., Veitía Rodríguez, N., García Rodríguez, L., Clavero García, J., & Romero Quintana, C. (2000). Inducción de mutaciones por radiaciones Gamma en el cultivo *in vitro* de brotes del cultivar Gran Enano (AAA). *Biotecnología Vegetal*, *1*, 45-50. https://biblat.unam.mx/es/revista/biotecnologia-vegetal/articulo/induccion-de-mutaciones-por-radiaciones-gamma-en-el-cultivo-in-vitro-de-brotes-del-cultivar-gran-enano-aaa

González Oramas, G., Alemán García, S., Garriga, M., Ortíz, R., & de la Fe, C. (2007). Radiosensibilidad a rayos gamma (^{60}Co) en brotes de henequén. *Biotecnología Vegetal*, *7*(2), 115-117. https://revista.ibp.co.cu/index.php/BV/article/view/365

Hernández-Muñoz, S., Pedraza-Santos, M. E., López, P. A., De La Cruz-Torres, E., Fernández-Pavía, S. E., Martínez-Palacios, A., & Martínez-Trujillo, M. (2017). Determinación de la DL_{50} y GR_{50} con rayos gamma (^{60}Co) en protocormos de *Laelia autumnalis in vitro*. *Agrociencia*, *51*(5), 507-524. https://agrociencia-colpos.org/index.php/agrociencia/article/view/1307

Ilyas, S., & Naz, S. (2014). Effect of Gamma irradiation on morphological characteristics and isolation of curcuminoids and oleoresins of cúrcuma longa L. *The Journal of Animal & Plant Sciences, 24*(5), 1396-

1404. https://www.thejaps.org.pk/docs/v-24-5/18.pdf

Latado, R. R. (1993). *Inducao e uso de mutacoes "in vitro" no melhoramento do Chrysanthemum morifolium Ram*. Universidade de Sao Paulo. https://teses.usp.br/teses/disponiveis/11/11137/tde-20220208-032802/

López Zada, M., Vázquez Becalli, E., & López Fleites, R. (1984). *Raíces y Tubérculos*. Pueblo y Educación.

Lozada Barrera, A. F. (2005). *Producción del cultivo de papa china (Colocasia esculenta) utilizando dos métodos de propagación asexual bajo cuatro niveles de fertilización orgánica*. Universidad de las Fuerzas Armadas - ESPE. https://repositorio.espe.edu.ec/bitstream/21000/5423/4/T-ESPE-IASA%20I-002856.pdf

Martirena-Ramírez, A., Veitía, N., García, L. R., Collado, R., Torres, D., Rivero, L., & Ramírez-López, M. (2018). Dosis óptima de radiaciones Gamma para la regeneración de plantas in vitro de *Phaseolus vulgaris* L. cultivar 'BAT-93'. *Biotecnología Vegetal*, *18*(1), 21-32. https://revista.ibp.co.cu/index.php/BV/article/view/572

Medero Vega, V. R., López Torres, J., Ventura Martín, J. de la C., Basail Pérez, M., Rayas Cabrera, A., Santos Pino, A., Beovides García, Y., Rodríguez Pérez, D., Torres Delgado, M., & Bravo Corrales, Y.(2014). Determinación de la dosis letal media in vitro para la inducción de mutaciones en malanga Colocasia. In *XIX Congreso Científico Internacional: VIII Simposio de Mejoramiento y Conservación de Recursos Fitogenéticos*. Cuba. http://ediciones.inca.edu.cu/files/congresos/2014/CD/memorias/ponencias/talleres/MCF/ra/MCF-O.19.pdf

Mukhtar Ali Ghanim, A., Spencer, M. M., & Thomas, W. (2021). Mejoramiento por mutaciones de cultivos propagados por semillas: selección parental, desarrollo de generaciones mutantes, detección de mutaciones, evaluación de mutantes y factores que influyen en el éxito. In M. M. Spencer-Lopes, B. P. Forster, & L. Jankuloski (coords.), *Manual de mejoramiento por mutaciones* (3ª ed.) (pp. 99-128). FAO y OIEA. https://doi.org/10.4060/i9285es

Nurilmala, F., Hutagaol, R. P., Widhyastini, I. M., Widyastuti, U., & Suharsono, S. (2017). Somaclonal variation induction of Bogor taro (*Colocasia esculenta*) by gamma irradiation. *Biodiversitas Journal of Biological Diversity*, *18*(1), 28-33. https://doi.org/10.13057/biodiv/d180105

Otahola Gómez, V., Aray, M., & Antoima, Y. (2001). Inducción de mutantes para el color de la flor en crisantemos (*Dendrathema grandiflora* (Ram.) Tzvelev) mediante radiaciones gamma. *UDO Agrícola*, *1*(1), 56-63. http://saber.udo.edu.ve/index.php/udoagricola/article/view/3434

Pérez Ponce, J. N. (1998). *Propagación y mejora genética de plantas por biotecnología.* Instituto de Biotecnología de las Plantas.

Ramírez, D., Ordaz, J. L., Mora, J., Acosta, A., & Serna B. (2010). *Nicaragua efectos del cambio climático sobre la agricultura*. CEPAL. https://hdl.handle.net/11362/25925

Robles Sánchez, R. (1986). *Genética elemental y fitomejoramiento práctico* (1ª ed.). Limusa.

Sahoo, B. B., Kole, P. C., & Sahoo, M. R. (2015). Effects of γ irradiation on leaf blight disease of some taro (*Colocasia esculenta* L. Schott) genotypes. *International Journal of Bio-resource and Stress Management*, *6*(1), 7-14. https://ojs.pphouse.org/index.php/IJBSM/article/view/641

Sarsu, F., Penna, S., Kunter, B., & Ibrahim, R. (2021a). Mejoramiento por mutaciones de cultivos propagados vegetativamente. In M. M. Spencer-Lopes, B. P. Forster, & L. Jankuloski (coords.), *Manual de mejoramiento por mutaciones* (3ª ed.) (pp. 131-144). FAO y OIEA. https://doi.org/10.4060/i9285es

Sarsu, F., Spencer-Lopes, M. M., Sangwan, R., & Penna, S. (2021b). Técnicas específicas para aumentar la eficiencia del mejoramiento por mutaciones: Métodos *in vitro* en el cambio del mejoramiento de plantas por mutación. In M. M. Spencer-Lopes, B. P. Forster, & L. Jankuloski (coords.), *Manual de mejoramiento por mutaciones* (3ª ed.) (pp. 171-186). FAO y OIEA. https://doi.org/10.4060/i9285es

Seetohul, S., Puchooa, D., & Ranghoo-Sanmukhiya, V. M. (2008). Genetic Improvement of Taro (Colocasia esculenta var esculenta) through in-vitro mutagenesis. *University of Mauritius Research Journal*, *13A*, 79-89. https://www.ajol.info/index.php/umrj/article/view/130901

Spencer-Lopes, M. M., Jankuloski, L., Mukhtar Ali Ghanim, A., Matijevic, M., & Kodym, A. (2021). Mutagénesis física. In M. M. Spencer-Lopes, B. P. Forster, & L. Jankuloski (coords.), *Manual de mejoramiento por mutaciones* (3ª ed.) (pp. 5-41). FAO y OIEA. https://doi.org/10.4060/i9285es

Valdez Balero, A., Orellana Pérez, P., Veitía Rodríguez, N., & Torres Rodríguez, D. (2004). Crecimiento, regeneración y radiosensibilidad de callos de caña de azúcar (*Saccharum spp*. hibrido var. "SP 70-1284") tratados con radiación gamma fuente ^{60}CO. *Biotecnología Vegetal*, *4*(3), 165-169. https://revista.ibp.co.cu/index.php/BV/article/view/419

Vasudevan, K., & Jos, J. S. (1990). Methods to enhance solid mutation frequency in Colocasia. *Current Scien-*

ce, *59*(4), 226-227. http://www.jstor.org/stable/24094796

Veitía, N., García, L., Bermúdez-Caraballoso, I., Orellana, P., Padrón, Y., & Torres, D. (2007). Efecto de las radiaciones gamma sobre callos de papa var. 'Desirée'. *Biotecnología Vegetal*, *7*(1), 57-61. https://revista.ibp.co.cu/index.php/BV/article/view/358