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Seed germination and seedling vigor of apaxtleco peppers in response to ^{60}Co gamma radiation

Germinación de la semilla y vigor de plántula de chiles apaxtlecos en respuesta a la radiación gamma ^{60}Co

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ABSTRACT

The gamma radiation effect on seed germination and seedling vigor of apaxtle chili was studied. The combined impact of seed irradiation doses using gamma rays from ^{60}Co (0, 50, 100, 150, 200, 250, and 300 Gy) was assessed on apaxtleco chili bell pepper genotypes (*Ancho chino* 1, *Ancho chino* 2, and *Ancho liso*) in a completely randomized design. Five replicates were used for germination tests in the laboratory, while ten replicates were employed for seedling emergence and vigor (M_1) in the greenhouse. Irradiation at 100 and 300 Gy stimulated seed germination in the laboratory, whereas 150 Gy led to reduced seedling emergence under greenhouse conditions. Seedling height generally decreased, except when exposed to 50 Gy. Seedling stem size (diameter and length) increased within the 0 to 150 Gy range, while fresh weight increased from 0 to 50 Gy and 250 to 300 Gy. Leaf number decreased beyond 250 Gy, while fresh weight increased at 50 and 300 Gy. Root length showed increments at 50 and 100 Gy. The outstanding genotype was *Ancho chino* 1. Obtained data provide insights into seed performance and seedling vigor of apaxtleco chili peppers under gamma ^{60}Co irradiation.

KEY WORDS: *Capsicum*, Germination, Mutagenesis, Radiation, Seed.

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RESUMEN

Se estudió el efecto de la radiación gamma en la germinación de la semilla y vigor de plántula de chiles apaxtlecos. Se estudió el efecto de la dosis de irradiación a la semilla con rayos gamma con ^{60}Co (0, 50, 100, 150, 200, 250 y 300 Gy) en genotipos de chile apaxtleco (*Ancho chino* 1, *Ancho chino* 2 y *Ancho liso*), en diseño completamente al azar, con cinco repeticiones para germinación (en laboratorio) y 10 para emergencia y vigor de plántula M_1 (en invernadero). La irradiación con 100 y 300 Gy estimuló la germinación en laboratorio, pero con 150 Gy se redujo en invernadero. La altura de plántula disminuyó, excepto con 50 Gy. El tamaño (diámetro y longitud) del tallo de plántulas aumentó con 0 a 150 Gy; y el peso fresco con 0 a 50 Gy y 250 a 300 Gy. El número de hojas disminuyó con más de 250 Gy y su peso fresco aumentó con 50 y 300 Gy. Mayor longitud de raíz hubo con 50 y 100 Gy. El genotipo sobresaliente fue Ancho chino 1. Los resultados aportan información del comportamiento de la semilla y el vigor de la plántula de chiles apaxtlecos por la irradiación gamma ^{60}Co.

PALABRAS CLAVE: *Capsicum*, Germinación, Mutagénesis, Radiación, Semilla.

Introduction

Chili (*Capsicum* spp.) is a crop of significant economic and nutritional importance globally (Contreras *et al.,* 2011; FAO, 2022). Endemic to Mexico and parts of Central and South America (Aguirre and Muñoz, 2015). *Capsicum* variants are highly adapted to diverse climates, soils, and altitudes (0 to 2,500 m). This adaptability has facilitated its widespread distribution (Pérez-Castañeda *et al.,* 2015). In Mexico, primarily five species of chili are cultivated: *C. annuum*, *C. chinense*, *C. pubescens*, *C. frutescens,* and *C. baccatum* alongside approximately 25 wild and semi-cultivated varieties (Aguilar-Rincón *et al.,* 2010); but *Capsicum annuum* L. holds the broadest distribution, morphological diversity, cultivated area, production, commercialization, and consumption. Its significance lies in its size, spiciness, flavor, aroma, and color, which are indispensable in Mexican gastronomy. Additionally, it serves various purposes in industries, medicine, and religion (Vázquez *et al.,* 2020). However, the greatest diversity of *Capsicum* is only known and used regionally or locally (Aguilar-Rincón *et al.,* 2010).

In the northern region of the state of Guerrero, Mexico, the Apaxtleco chili bell pepper (*Ancho liso*, *Ancho chino*, *Delgado liso*, and *Carricillo*) is cultivated, considered endogenous (native) material of cultural and economic importance in Apaxtla de Castejón, Guerrero (Aguilar-Rincón *et al.,* 2010; Vázquez-Casarrubias *et al.,* 2011). Producers traditionally cultivate this species under rainfed conditions during the spring-summer cycle (S-S cycle), in small areas, employing family labor for cultural work. The genetic variability of Apaxtleco chili has been altered by the selection and management of producers, influencing seed quality, genetic purity, viability, and germination, as well as plant vigor. Consequently, the fruit exhibits changes in size, shape, color, flavor, and odor (Aguilar-Rincón *et al.,* 2010). Additionally, climatic, biological, and technical factors such as periods of drought or precipitation, the incidence of pests and diseases, poor nutrition, and weed management contribute to these effects (Aguilar-Rincón *et al.,* 2010; Contreras *et al.,* 2011).

Under natural conditions, apaxtleco chili seed germination decreases by 24 %, so large quantities are sown to meet the seedling demand of producers (Hernández-Verdugo *et al.,* 2010). The low germination rate in some *Capsicum* species, even under favorable conditions, is due to the impermeability and hardness of the seed coat or limited endosperm permeability and embryo dormancy (Bañuelos *et al.,* 2008; Araiza *et al.,* 2011). Seed quality and vigor are determined by genetic, physiological, morphological, and phytosanitary factors (Mazvimbakupa *et al.,* 2015). Given this, mutagenesis with gamma irradiation can be a tool to increase and accelerate seed germination (López-Mendoza *et al.,* 2012; Rangel-Castillo *et al.,* 2022; Warade *et al.,* 2022).

The biological effect of gamma rays is based on the interaction with atoms or molecules in the cell, particularly water, to produce free radicals (*i.e.*, H^+, OH, H_2O_2) (Borzouei *et al.,* 2010; Esnault *et al.,* 2010), which modify cell components and alter plant anatomy, biochemistry, morphology, and physiology depending on the radiation dose (Jan *et al.,* 2012; Song *et al.,* 2012). These changes in plant cell structure and metabolism cause dilation of thylakoid membranes, disruption of photosynthesis, modulation of the antioxidant system, and accumulation of phenolic compounds (Marcu *et al.,* 2013a; Wang *et al.,* 2017; Saputro *et al.,* 2019). Low doses (< 200 Gy) of gamma irradiation stimulate physiological processes of seed germination and seedling development (Wiendl *et al.,* 2013; Araujo *et al.,* 2016; Jaipo *et al.,* 2019 they also accelerate cell proliferation, enzymatic activity, and cell growth (Macovei *et al.,* 2014). In contrast, high doses alter protein synthesis, hormone balance, and water movement by gas exchange in leaves and seedling enzymatic activity (Macovei *et al.,* 2014). Research in chili crops determined seed radiosensitivity and plant vigor, disease resistance, yield, and fruit quality (López-Mendoza *et al.,* 2012; Jo *et al.,* 2016; Aisha *et al.,* 2018; Thisawech *et al*. 2020; Meitei, *et al.,* 2020). Therefore, this research aimed to evaluate the effect of gamma ^{60}Co irradiation on seed germination and seedling vigor in apaxtleco chili genotypes. The hypothesis was that at least one dose of radiation applied to the seed stimulates germination and vigor traits of at least one apaxtleco chili genotype.

Materials and methods

Seeds of three genotypes of apaxtleco chili (*Capsicum annuum* L.) (*Ancho chino 1*, *Ancho chino 2*, and *Ancho liso*) were used; obtained from commercially mature fruits (red color) in a field collected at Apaxtla de Castrejón, Guerrero. The fruits and seeds exhibited the characteristics described by Aguilar-Rincón *et al.* (2010) and Croseños-Palazin *et al.* (2023). Seeds were irradiated

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with a Transelektro LGI-01 irradiator at the National Institute for Nuclear Research (ININ-Mexico), in Mexico State. The combined effect of the irradiation dose (0, 50, 100, 150, 150, 200, 250, 250, and 300 Gy of gamma ^{60}Co rays, in 5 g of seed) on germination, emergence, and seedling vigor of three apaxtleco chili genotypes (*Ancho chino 1*, *Ancho chino 2*, and *Ancho liso*) was studied, which resulted in 21 treatments. These were distributed in a completely randomized design, with five replicates for germination in a container under laboratory conditions and ten replicates for the variables related to seedling emergence and vigor M_1 in a tray, under greenhouse conditions. The irradiated seeds were sown in two ways; the first one, depositing 20 seeds per 15 x 15 cm translucent plastic container covered with medium pore filter paper and kept in the germination chamber, at a temperature of 25 °C ± 2 °C; photoperiod of 8 h light and 16 h dark and watered every two days with distilled water, the experimental unit was a container with 20 seeds. The second, depositing two seeds per cavity in expanded polypropylene trays of 200 cavities filled with peat, the experimental unit consisted of ten seedlings, these were manually irrigated with drinking water (pH 7.6 and EC of 0.5 dS m^{-1}) twice a day from sowing until the end of the experiment. The seedlings were housed in a greenhouse whose prevailing environmental conditions were: humidity of 58 %, minimum temperature of 24 °C and maximum temperature of 42 °C. Seedling sensitivity was determined at 24 days after sowing (das) in the laboratory based on the days and germination percentage, while in the tray, the days and emergence percentage in the greenhouse were recorded; seedling vigor M_1 in the tray was quantified at 30 days after emergence by: seedling height (cm) with a flexometer (Truper®), from the base of the stem to the youngest leaf; stem diameter (mm) with a vernier (Truper® model CAL-6MP), at 1 cm from the base of the root and the first leaf; length (cm) and fresh weight of the stem (g), the first was measured with a flexometer from the base of the stem to the apex of the stem and the weight was determined with a digital scale; leaf number and fresh weight (g) of leaves were recorded with a digital scale (Torrey® L-PCR series); length (cm) and root fresh weight (g), the former was measured with a flexometer from the stem base to the longest root and the weight was determined with a digital scale. An ANOVA of the treatments resulting from the combination of radiation doses (D) and genotype (G) of apaxtleco chili was performed for each variable. Means were compared using Tukey's test ($p \leq 0.05$) with the statistical program SAS (Statistical Analysis System), version 9.1 (SAS Institute, 2002).

Results and Discussion

Seed germination, emergence, and seedling vigor parameters of M_1 exhibited statistical significance ($p \leq 0.05$) across chili bell pepper genotypes concerning irradiation dose (Tables 1 and 2). In crops such as tomato (*Solanum lycopersicum* L.) (Álvarez *et al.,* 2011; Álvarez *et al.,* 2012), chili (*Capsicum* spp.) (López-Mendoza *et al.,* 2012; Rangel-Castillo *et al.,* 2022), maize (*Zea mays* L.) (Marcu *et al.,* 2013b), wheat (*Triticum aestivum* L.) (Albokari *et al.,* 2012; Khah & Verma, 2017), bean (*Phaseolus vulgaris* L.) (Ulukapi & Ozmen, 2018; Jafarov *et al.,* 2020), and okra (*Abelmoschus esculentus* L.) (Hegazi & Hamideldin, 2010), different radiation doses to seeds have been reported to randomly affect plant anatomy and morphology. The effect depends on various factors, including species, cultivar, developmental stage, tissue architecture, genome organization, and aspects related to the quality (dose and duration) of radiation exposure (Jan *et al.,* 2012; De Micco *et al.,* 2014).

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Table 1. Analysis of variance for seed germination in the laboratory and seedling emergence in the greenhouse of three apaxtleco chili genotypes.

Sources of variation	Degrees of freedom	Germination in container	Days to germination in container	Tray emergency	Days to emergency in tray
TRAT	20	154.40*	38.11*	321.99*	37.29*
CV (%)	--	3	11	11	9

TRAT = Treatments. CV = Coefficient of variation. * = Significant, ns = Not significant, $p \leq 0.05$.

Table 2. Analysis of variance for seedling vigor M_1 of three apaxtleco chili genotypes in greenhouse.

Sources of variation	DF	SH	SD	SL	SFW	NL	FWL	RL	FWL
TRAT	20	4.47*	0.77*	17.08*	0.020*	6.85*	0.021*	32.08*	0.004*
CV (%)	--	13.03	16.67	23.31	45.63	18.82	50.44	24.10	111.68

DF = Degrees of freedom. TRAT = Treatments. CV = Coefficient of variation. SH = Seedling height. SD = Stem diameter. SL = Stem length. SFW = Stem fresh weight. NL = Number of leaves. FWL = Fresh weight of leaves. RL = Root length. RFW = Root fresh weight. * = Significant, ns = Not significant, $p \leq 0.05$.

Seed germination

Seed germination varied significantly depending on genotype and the applied radiation dose (Table 1; Figures 1 and 2). Under laboratory conditions, seed germination of *Ancho chino 2* irradiated with 300 Gy showed higher rates compared to *Ancho chino 1* and *Ancho liso* genotypes across all radiation doses, except for the germination achieved in *Ancho chino 1* with non-irradiated seeds (97 %) and those irradiated with 250 and 300 Gy (96 %). Conversely, in other treatments, germination decreased by 7 to 13 %. *Ancho liso* seeds exhibited higher sensitivity to gamma radiation, resulting in lower germination rates (66 %). However, this genotype demonstrated increased germination when seeds were treated with 50 and 150 Gy (92 %) (Figure 1a).

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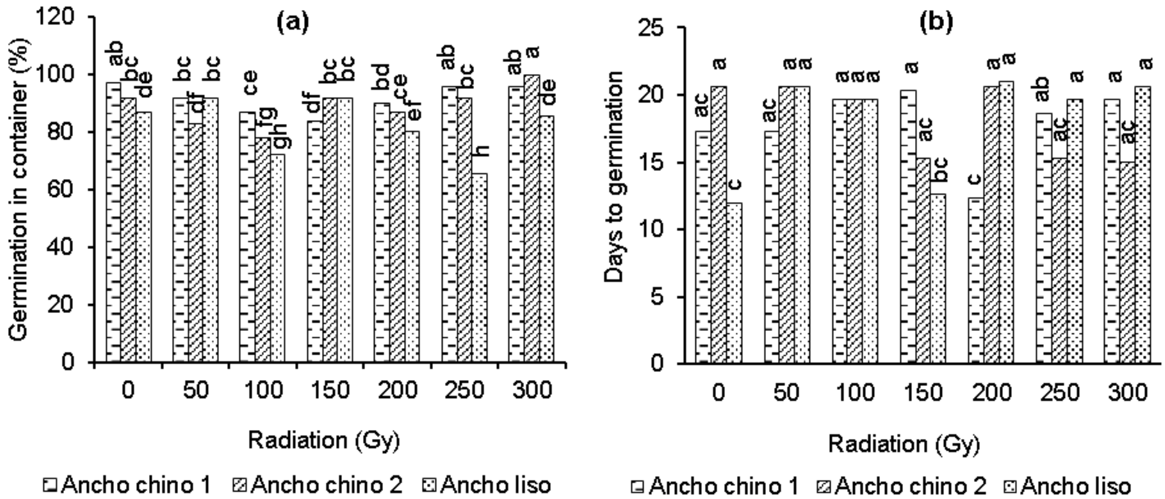

Figure 1. Effect of gamma ^{60}Co radiation on the percentage (a) and time (b) of seed germination of three genotypes of apaxtleco chili, established in containers under laboratory conditions.

Means with different letters are statistically different (Tukey, *p ≤ 0.05*). SMD (a) = 7.59. SMD (b) = 6.10. SMD = Minimum significant difference.

Regarding the days to germination, the seeds of the *Ancho liso* genotype, both not irradiated and irradiated with 150 Gy, had the shortest germination time, with 12 and 13 days, respectively. The same behavior was observed with the days to germination of the seeds of *Ancho chino 1* irradiated with 200 Gy, germinating earlier (12 days) than the rest of the treatments (Figure 1b). In comparison, the seeds of *Ancho chino 2*, without irradiation or irradiated with low doses (50 and 100 Gy), delayed this process up to 21 days. However, germination of *Ancho chino 2* seeds irradiated with 200, 250, and 300 Gy took 15 days, respectively. In contrast, in the *Ancho chino 1* genotype, except for the 200 Gy dose, the non-irradiated seeds irradiated with the rest of the doses had a germination period ranging from 17 to 20 days. The effect of gamma radiation has also been reported in seeds of *Lathyrus chrysanthus*, where doses of 50 to 250 Gy stimulated germination in laboratory conditions, with the doses of 100 and 150 Gy standing out (Beyaz *et al.,* 2016).

In the greenhouse, gamma irradiation of the seeds influenced the seedling emergence of M_1 of the evaluated genotypes, with doses ranging from 0 to 100 Gy showing the most significant effects (68 % to 73 %). In contrast, the dose of 150 Gy decreased emergence by 16 % to 23 % in both genotypes. Specifically, seeds of *Ancho chino 1* without irradiation (84 %) and irradiated with 250 Gy (78 %) and 300 Gy (75 %) exhibited higher seedling emergence rates, while in *Ancho chino 2*, more seedlings emerged from seeds without irradiation (83 %) and those irradiated with 100 Gy (81.22 %). *Ancho liso* displayed a different pattern, with seedlings from seeds irradiated with 50, 100, and 200 Gy showing 72 % to 73 % emergence (Figure 2a). Similarly, the combined effect of radiation with the apaxtleco chili genotypes was observed at the time of seedling emergence

M_1, with seeds of *Ancho chino 1* treated with 100 and 150 Gy favoring quicker emergence (14 to 17 days). In contrast, non-irradiated seeds of *Ancho liso* emerged 16 days after sowing, whereas emergence time for the rest of the treatments ranged from 20 to 26 days. These results differ from those reported for *Chile de Agua* (*Capsicum annuum* L.) seeds irradiated with 0 to 120 Gy, where germination was not stimulated (López-Mendoza *et al.,* 2012). Additionally, they contrast with findings from Rangel-Castillo *et al*. (2022) and Omar *et al*. (2008) in seeds of two varieties of chili (*C. annuum*); the former indicated that doses of 100 to 400 Gy decreased seed germination by 33 % in jalapeño bell pepper, while the latter mentioned that seeds of the Kulai cultivar irradiated with 300 and 400 Gy had germination rates (36 % to 42 %) similar to non-irradiated seeds (43 %). However, high doses (500, 600, and 800 Gy) decreased this indicator, with 800 Gy notably inhibiting germination, attributed to the formation of free radicals altering biochemical and physiological processes in the irradiated seeds (Esnault *et al.,* 2010). In other words, high irradiation doses cause histological and cytological changes, disruption, and disorganization of the seed coat, and alteration or suppression of cell division in meristematic zones during germination (FAO/IAEA, 2021).

Obtained data suggest that particular intermediate doses stimulate germination, which is related to the species and the degree of seed deterioration. In this regard, the difference in germination percentage between irradiation doses is attributed to the inhibition or stimulation of biochemical and physiological processes (Hasbullah *et al.,* 2012), which are related to the activation of RNA and protein synthesis (Piri *et al.,* 2011), and instability in cell development and division (Oladosu *et al.,* 2016; Thole *et al.,* 2011), caused by an increase in respiration rate or auxin metabolism. However, a higher germination percentage with high doses is related to the elimination of bacterial and fungal populations (spores) present in the seed (Rassam *et al.,* 2012).

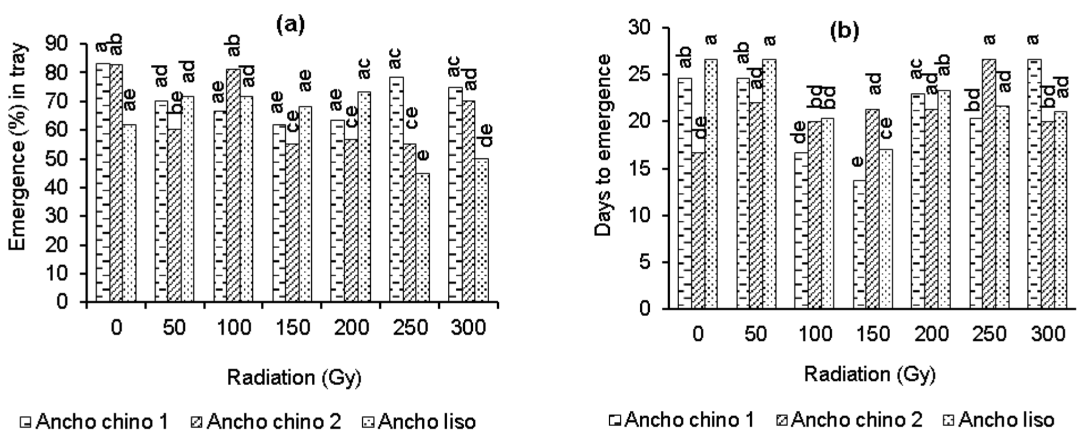

Figure 2. Effect of gamma ^{60}Co radiation on the percentage (a) and time (b) of seed germination of three apaxtleco chili genotypes, established in a tray under greenhouse conditions.

Means with different letters are statistically different (Tukey, $p \leq 0.05$). SMD (a) = 22.84. SMD (b) = 6.22. SMD = Minimum significant difference.

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Seedling vigor

Seed irradiation significantly affected some growth parameters in M_1 seedlings of apaxtleco chili peppers (Table 2). The seedling height of the three genotypes decreased from 9 % to 67 % in those from seeds irradiated with 100 Gy onwards, mainly in the genotypes *Ancho chino 2* and *Ancho liso*. In contrast, the control (non-irradiated) seedlings of *Ancho chino 1* and *2* were higher, whereas in *Ancho liso*, they were higher when seeds were irradiated with 50 Gy (Figure 3a). Similar behavior was reported in *Glycine max*, where seedling height decreased by 50 % with more than 200 Gy (Alikamanoglu *et al.,* 2011); whereas, doses higher than 300 Gy reduced plant vigor in two varieties (TC 9-6 and A-4) of cowpea (*Vigna unguiculata*) (Lemus *et al.,* 2002). In contrast, *C. annuum* seedlings from seeds irradiated with low doses were similar to the control in height, while high doses (600 and 800 Gy) reduced it considerably (Omar *et al.,* 2008).

Stem diameter and length improved with 0 to 150 Gy and fresh weight was stimulated with low (0 to 50 Gy) and high (250 to 300 Gy) doses in both genotypes, however, the gain in the first and third parameters was greater in *Ancho chino 1* and *Ancho liso* seedlings (Figure 3b, d). On the contrary, the three genotypes had similar stem lengths (4.50 to 4.86 cm) (Figure 3c). In the three chili genotypes, the control seedlings and those treated with 50 and 100 Gy presented greater diameter and stem length; except for fresh weight, where the doses of 250 and 300 Gy stimulated this indicator only in *Ancho liso* seedlings (Figure 3d), since gamma irradiation of the seed originates seedlings with lower biomass (Omar *et al.,* 2008). In the same context, growth stimulation by low doses is due to hormonal signaling changes in cells or by increasing the antioxidant capacity of cells to overcome stress factors, such as fluctuating light intensity and temperature prevailing during growth (Liu *et al.,* 2008; Lagoda, 2012). In contrast, growth inhibition by high doses is attributed to cell cycle arrest in the G2/M phase during somatic cell division, auxin synthesis, and genome impairment (Hernández-Muñoz *et al.,* 2019; FAO/IAEA, 2021).

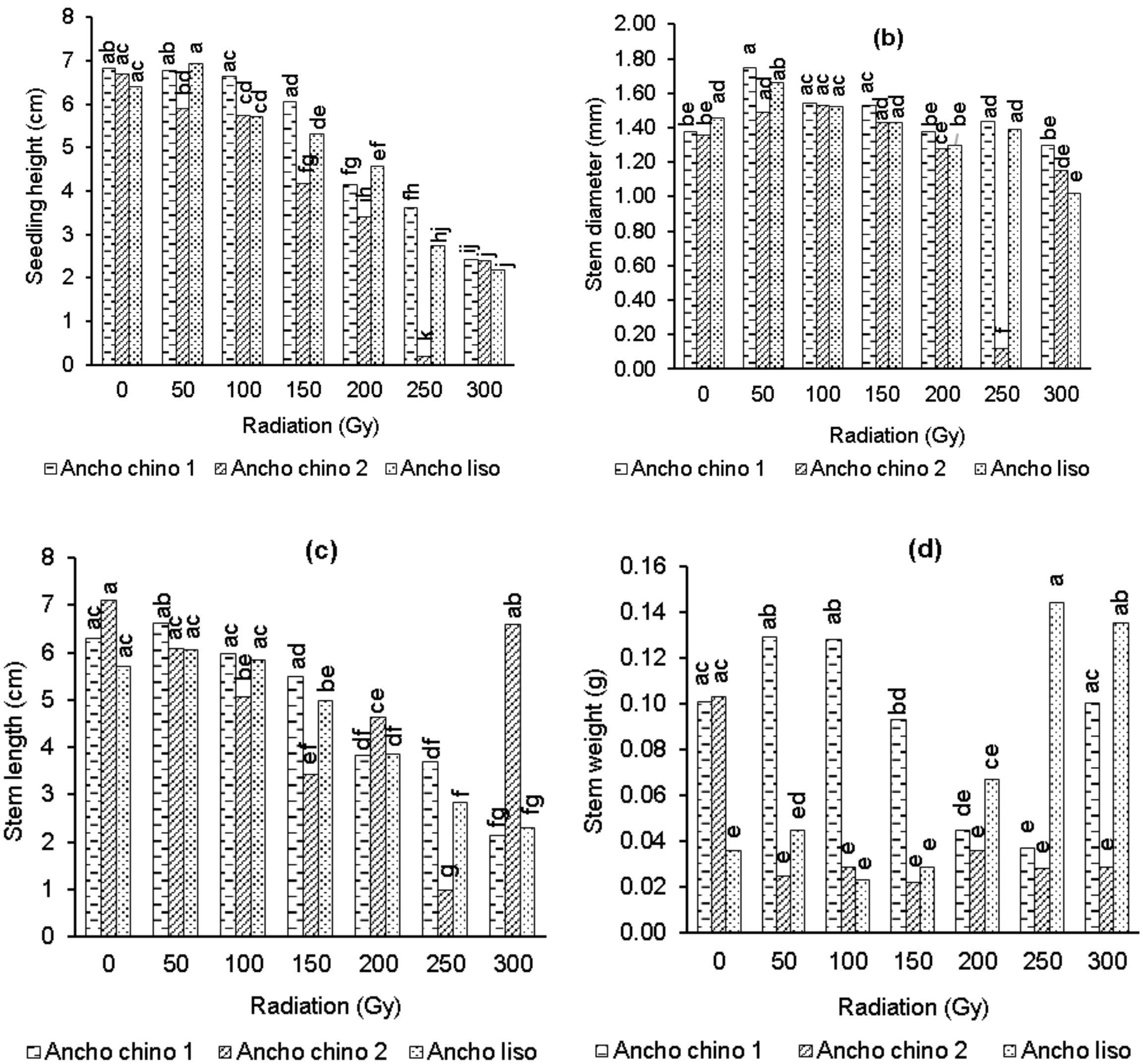

Figure 3. Effect of gamma ^{60}Co radiation on height (a) and stem size (diameter (b), length (c), fresh weight (d)) of the seedlings of three apaxtleco chili genotypes.

Means with different letters are statistically different (Tukey, *p ≤ 0.05*). SMD (a) = 0.99. SMD (b) = 0.37. SMD (c) = 1.79. SMD (d) = 0.05. SMD = Minimum significant difference.

On the other hand, the number of leaves was reduced with doses higher than 250 Gy, which limited their formation (Figure 4a), mainly in the *Ancho chino 2* genotype from seeds irradiated with 250 Gy, compared to the *Ancho chino 1* genotype, which produced a greater number of leaves when the seeds were irradiated with 50 to 250 Gy and without irradiation. Similarly, compared to *Ancho liso* with 0 to 200 Gy. In contrast, leaf fresh weight increased in *Ancho chino 1* seedlings

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from seeds irradiated with 50, 200, and 300 Gy (Figure 4b). However, irradiation reduced leaf weight in *Ancho chino 2* seedlings, mainly when seeds were irradiated with 250 Gy. The same response was shown by the *Ancho liso* genotype, where all doses reduced leaf weight (Figure 4b). A similar effect was reported in soybean seedlings, where seed irradiation (0 to 500 Gy) decreased the number of leaves (Kara *et al.,* 2016) but did not affect seedling fresh weight, with mutants (100 to 500 Gy) showing similar weight to the control (Alikamanoglu *et al.,* 2011). In contrast, irradiation with 0 to 300 Gy of cowpea bean seeds (TC 9-6 and A-4) did not affect plant foliage; however, doses of 400 to 750 Gy decreased leaf formation (Lemus *et al.,* 2002).

Radiation stimulation (low doses < 100 Gy) in biomass formation is associated with genetic (random DNA changes), cytological, biochemical, physiological, and morphogenetic alterations in cells and tissues. These alterations include increased chlorophyll, sugar, and total carbon (C) (Jan *et al.,* 2013; Ulukapi & Ozmen, 2018). In contrast, decreased foliage is associated with alterations in protein synthesis, hormone balance, leaf gas exchange, water exchange, and enzyme activity (Lagoda, 2012; Macovei *et al.,* 2014), mainly when seeds are irradiated with more than 200 Gy (Borzouei *et al.,* 2010). The importance of biomass lies in its role as an indicator of plant growth; it expresses the balance between photoassimilate production and respiration (Reyes-Perez *et al.,* 2013). In this research, some radiation doses favored leaf formation and leaf weight, especially in the *Ancho chino 1* genotype.

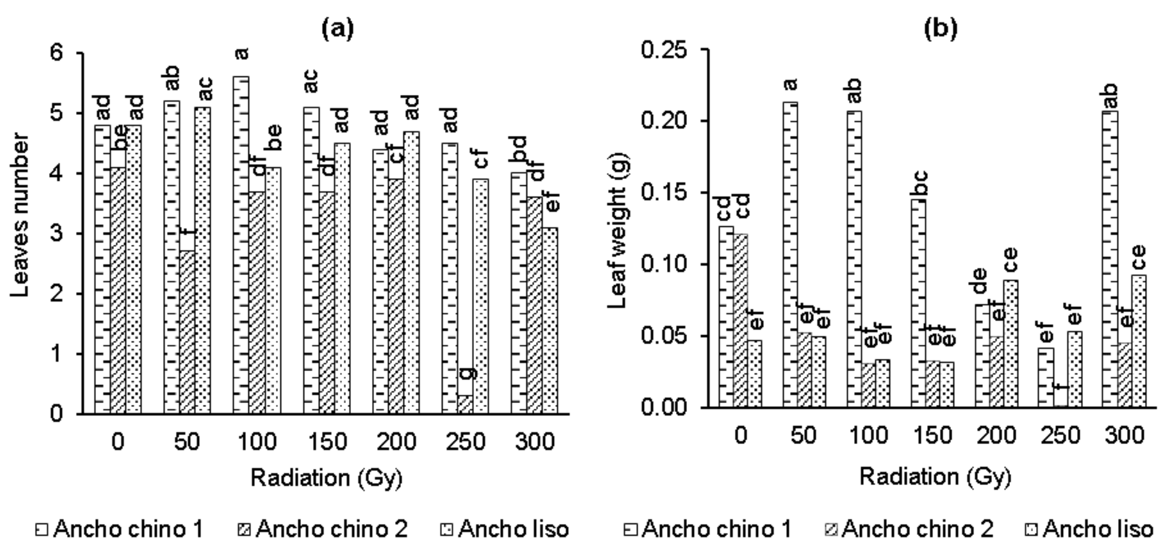

Figure 4. Effect of gamma ^{60}Co radiation on the number (a) and fresh weight (b) of leaves in the seedlings of three apaxtleco chili genotypes.

Means with different letters are statistically different (Tukey, *p ≤ 0.05*). SMD (a) = 1.25. SMD (b) = 0.07. SMD = Minimum significant difference.

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Root length was altered by gamma radiation (Table 2). Seedlings from seeds irradiated with 50 and 100 Gy (9.18 and 9.57 cm) and non-irradiated seeds (9.01 cm) had greater root length, whereas root fresh weight was similar between seedlings from non-irradiated and irradiated seeds (0.03 to 0.07 g) (Figure 5a). However, the most outstanding genotype in both aspects was *Ancho chino 1* (9.20 cm and 0.10 g). Therefore, radiation with 50 and 100 Gy increased root size in *Ancho chino 1* and *2* seedlings; in contrast, similar results to those in *Ancho chino* 1 were reported in *Solanum lycopersicum*, where seeds irradiated with 5 to 20 Gy produced seedlings with large roots, 15 % higher than the control (Álvarez *et al.,* 2011; Álvarez *et al.,* 2012). In jalapeño bell pepper, seeds irradiated with 100 to 400 Gy generated M_1 seedlings with lower radicle fresh weight, but with similar responses between the mutants and the control (Rangel-Castillo *et al.,* 2022). Omar *et al*. (2008), mentioned that doses of 300 and 500 Gy to *Capsicum annuum* seeds did not affect root length and weight in M_1 seedlings; they were similar in size to the control seedlings. However, irradiation with 600 and 800 Gy negatively affected both parameters. Meanwhile, irradiation of *Hordeum vulgare* seeds with 700 to 1200 Gy did not modify root length (Nasab *et al.,* 2010).

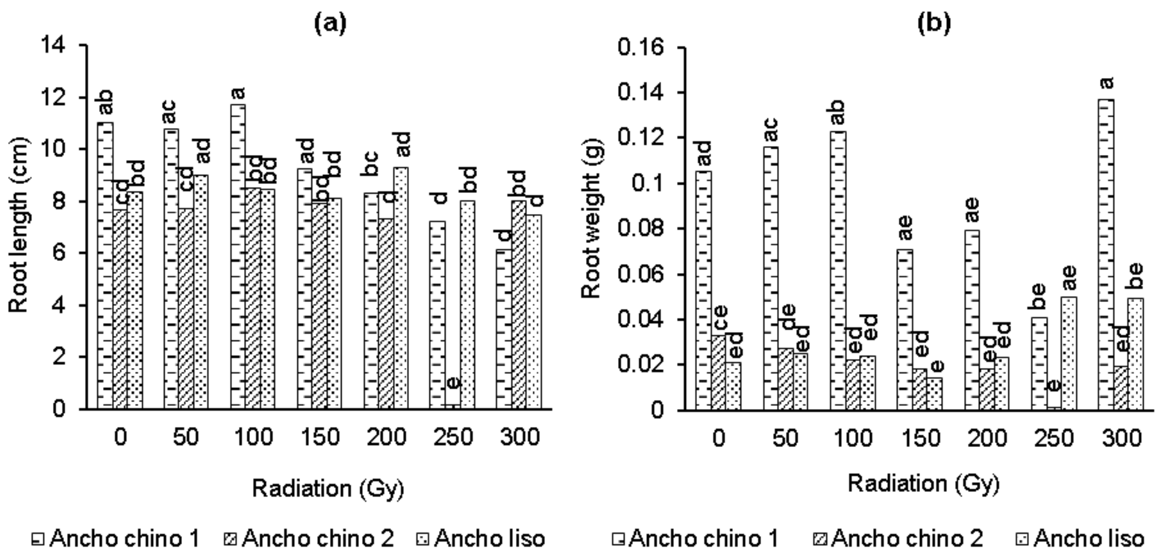

Figure 5. Effect of gamma ^{60}Co radiation on seedling length (a) and root weight (b) of three apaxtleco chili genotypes.

Means with different letters are statistically different (Tukey, $p \leq 0.05$). SMD (a) = 3.17. SMD (b) = 0.09. SMD = Minimum significant difference.

The heterogeneous behavior of seedling vigor parameters in apaxtleco chili is related to individual and random events in the genome by radiation, where some traits are enhanced. In contrast, others are suppressed (Viana *et al.,* 2019). Similarly, the optimal dose to induce favorable mutations depends on the susceptibility of the plant and the irradiated organ. In this regard,

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Meitei *et al*. (2020) pointed out that, at higher doses of gamma radiation, chromosomal alterations with negative effects on plant development and physiology increase; however, mutations with desirable effects can be inherited for several generations; therefore, to identify these changes, evaluation of morphological and physiological behavior in each generation is required.

Conclusions

Seed irradiation with 250 Gy stimulated the germination of the chili peppers *Ancho chino 1* and *2*, while with 150 and 200 Gy, the seed germination times of *Ancho chino 1* and *Ancho liso* were reduced under laboratory conditions. Seed irradiation decreased seedling emergence of the genotypes in trays by up to 23 % under greenhouse conditions. Gamma radiation doses to seeds greater than 100 Gy limited seedling height of *Ancho chino 1* and *Ancho liso* chili peppers, but doses greater than 250 Gy affected leaf formation in *Ancho chino 2* seedlings. Stem size (diameter, length, and weight) and root length of M_1 seedlings increased with low doses (50 to 100 Gy) of radiation, while doses of 200 and 300 Gy favored the leaf weight of *Ancho liso*.

The results of this research provide information on the behavior of the seed and seedling vigor of Apaxtleco chili peppers in response to gamma ^{60}Co irradiation, as there are currently no studies that allow us to determine their current level and thus design programs for the conservation and use of these genotypes.

Authors' contributions

The conceptualization of the work and methodological development were carried out by OMAO, JESL, and MICP. Experimental validation and analysis of results were performed by OMAO, JESL, and MICP. The writing and preparation of the manuscript were conducted by OMAO, JESL, and MICP. Revision and editing were undertaken by MER, MVV, and ARRG.

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Conflict of interest

The authors declare that they have no conflict of interest.

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