Growth dynamics of morphological and reproductive traits of *Physalis peruviana* L. *M*<sub>1</sub> plants obtained from seeds irradiated with Gamma rays

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**Abstract**

There is an increasing interest in the development of uchuva (*Physalis peruviana* L.) cultivars adapted to greenhouse farming. Sexual behavior makes it difficult to obtain uniform commercial uchuva cultivars by conventional breeding methods. Mutations induced by gamma rays is an alternative approach. *M*<sub>1</sub> plants derived from 14 irradiation *<sup>60</sup>Co* doses, from 0 to 275 Gy, that were applied to uchuva seeds were evaluated. Recorded data included days to first flower and growth dynamics (four to seven samplings) of morphological traits (plant height, stem diameter, basal stems) and reproductive traits (floral buds, flowers and green fruits). Treatments were distributed in a completely randomized blocks experimental design with six replications, in a greenhouse. The experimental unit was a single *M*<sub>1</sub> plant. Statistical differences were found for irradiation doses, growth samplings, and its interaction. Growth dynamics results indicate that all traits showed a linear increase with plant age (*R*<sup>2</sup> = 0.92* to 0.98**), but the effect of the irradiation doses on morphological and reproductive traits was no linear. Irradiation reduced plant height by 79%. *M*<sub>1</sub> plants developed from irradiated seeds at doses of 125, 175 and 200 Gy showed greater stem diameter, with more basal stems, floral buds, flowers and green fruits than the control. It is concluded that intermediate irradiation doses had a stimulating effect on vegetative growth and fruiting traits of *M*<sub>1</sub> uchuva plants.

**Keywords:** crop breeding; genetic variability; horticultural crops; mutagenesis; uchuva

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Received: 05 Dec 2019. Received in revised form: 17 Mar 2020. Accepted: 20 Mar 2020. Published online: 31 Mar 2020.
Introduction

Uchuva (Physalis peruviana L.) also known as golden berry, is a perennial species that grows wild in tropical highlands (1500 to 3000 m, altitude) of Chile and Colombia (Rodrigues et al., 2009, Fischer et al., 2011). Mature fruits are small (2.5 cm diameter), resembling mini-tomatoes (Solanum lycopersicum L.), with colors varying from yellow to orange and a bitter-sweet flavor. Fruits are consumed fresh and are high in fiber, provitamins A and C, iron, phosphorus and antioxidants (Fischer, 2000).

Uchuva can be sexually reproduced although vegetative propagation techniques (cutting) can also be used. Sexual behavior makes it difficult to obtain uniform commercial uchuva varieties by conventional breeding methods because half of the flowers are open-pollinated, favoring allogamy (Santana and Angarita, 1997) while the rest are self-pollinated, as an autogamous species (Lagos et al., 2008).

Natural mutations are random changes in DNA that occur in low frequency and spontaneously. The induction of mutations is used in plant breeding to increase genetic variability, which allows the subsequent application of selection methods of individuals with outstanding characteristics (Fuchs et al., 2002, Honda et al., 2006). Artificial mutations may be induced by chemical and physical mutagens. The latter group refers to the application of X-rays, gamma irradiation (Mohan Jain, 2006; Yamaguchi et al., 2008), ultraviolet rays (Ahloowalia and Maluszynski, 2001), and carbon ion-beam irradiation (Wu et al., 2009, Matsumura et al., 2010). Mutagenic agents produce structural, phenotypic and developmental alterations in cells, tissues and organs (Wi et al., 2005). Drastic alterations are usually lethal, while slight changes might be favorable for some traits related to the growth, development and reproduction of the plant.

In particular, gamma rays irradiation influences the growth and development of the plants, causing genome instability of cells and tissues, which produces cytological, biochemical, physiological and morphological changes through the production of free radicals in the cells (Kim et al., 2004; Wi et al., 2005). The use of high doses of this type of radiation inhibits plant growth (Aladjadjiyan, 2007; Canul-Ku et al., 2012), while low and intermediate doses can have a positive effect, by increasing cell proliferation, improving seed germination, cell growth, enzymatic activity, resistance to stress and yield (Chakravarty and Sen, 2001; Baek et al., 2005; Kim et al., 2005). When radiation induces mutations in a cell, there is a risk that a favorable mutation will be accompanied by undesirable genetic changes (Otahola-Gómez et al., 2001).

Results regarding the response of P. peruviana to gamma irradiation are scarce. Caro-Melgarejo et al. (2012) analyzed the effects of irradiation doses from 50 to 300 Gy applied to vegetative buds of this species on morphological and cytogenetics traits of the regenerated plants. They observed that doses between 100 and 200 Gy produced the largest phenotypic variability while doses higher than 200 Gy had negative effects. As for P. peruviana and P. angulata (L.) when doses of 200, 400 and 500 Gy applied to seeds were compared, it was observed that the dose of 200 Gy increased the growth of the M1 plants while doses greater than 200 Gy inhibited it (Raghava and Raghava, 1989). Literature references regarding uchuva traits measured throughout the biological cycle of the plant in order to monitor the effect of the application of artificial mutagens were not found.

There is an increasing interest in the development of uchuva cultivars adapted to greenhouse farming, as other Solanaceae species do. Therefore, early maturity, high yield and plant uniformity should be some of the agronomic traits of interest involved in a breeding program in this species. The aim of the present research was to determine the growth dynamics of morphological and reproductive traits of M1 plants of Physalis peruviana L. originated from seeds irradiated with gamma rays in order to analyse the relationship between irradiation doses and plant growth samplings as well as to identify the best radiation doses for each trait.
Materials and Methods

Biological material and applied treatments

Uchuva seeds from 'Ecotipo Colombia' were irradiated with $^{60}$Co gamma rays with a Transelektro irradiator (Model LGI-01, Hungary) at the Instituto Nacional de Investigaciones Nucleares, located at Ocoyoacac, Mexico. The irradiation treatments applied to the seed were 14 doses of $^{60}$Co gamma rays (0, 5, 10, 20, 50, 75, 100, 125, 150, 175, 200, 225, 250 and 275 Gy).

Experimental unit

In August 2015, 100 seeds of each dose were sown in expanded polystyrene trays with peat as a substrate, and irrigated with potable water (pH 7.6). In October 2015, the best six M$_1$ seedlings were selected in each treatment. After that, M$_1$ plants were distributed in a completely randomized experimental design, with six replications. The experimental unit was an M$_1$ plant, placed in a black polyethylene bag of 9 L size. Tezontle (volcanic rock) was the main substrate support; other substrate characteristics were: granulometry, 1 to 10 mm; average apparent density, 0.82 g cm$^{-3}$; total porosity, 50%; aeration porosity, 45%; readily available water, 5.42%; cation exchange capacity, none; electrical conductivity, close to zero (Gutiérrez-Castorena et al., 2011). A tunnel-type greenhouse with UVII-720 polyethylene cover and galvanized steel structure, with lateral ventilation, located in Montecillo, State of Mexico was used.

The M$_1$ plants were held upright by tutoring. The Steiner solution was used at 50% of its original ionic strength; pH of the solution was adjusted to 6.0 (Gastelum-Osorio et al., 2013). Average monthly environmental conditions that prevailed from October 2015 to February 2016 were: light intensity, 652.21 μmol m$^{-2}$ s$^{-1}$; maximum temperature, 37 °C; and minimum temperature, 8 °C.

Morphological and reproductive traits

In each M$_1$ plant, the first record of plant height (PH, cm; from the substrate level to the apex of the longest branch) and stem diameter (SD, mm; at 2 cm from the base of the stem), was registered 25 days after transplant (dat). Corresponding initial records for the number of basal stems (NBS) were at 31 dat, 55 dat for floral buds (NFB) and 70 dat for flowers (NF) and green fruits (NGF). Afterwards, all traits were registered every 15 days. Therefore, data from 24 to 42 individual M$_1$ plants were involved in each growth sampling average. In addition, days to the first flower were recorded.

Statistical analysis

A combined analysis of variance was applied for each trait (except for days to the first flower). Sources of variation were: irradiation doses, growth samplings and irradiation doses × growth samplings interaction. Tukey test ($p \leq 0.05$) was used for means comparisons. Analyses were carried out with the statistical program SAS, version 9.1 (SAS Institute, 2002). In addition, linear regression was applied to growth samplings data for each trait, while polynomial regression was performed over irradiation doses data.

Results and Discussion

Significant differences ($p \leq 0.05$) for irradiation doses, growth samplings and the doses × growth sampling interaction were found in the combined analysis of variance for all traits (Table 1).

Growth dynamics

The expression of all traits related to the growth dynamics of vegetative and reproductive traits, of $P$. peruviana increased according to a linear model ($R^2$ between 0.92* and 0.98**) as the age of the M$_1$ plants
increased (Figure 1). This means that averaged over the 14 irradiation doses, the growth rate of these traits was constant throughout the time. The highest expression occurred in the last growth sampling, which is attributed to the indeterminate and perennial habit of this species (Fischer et al., 2011).

Table 1. Statistical significance of the sources of variation for morphological and reproductive traits of M₁ plants of Physalis peruviana L.

| Source                | Morphological and reproductive traits |
|-----------------------|---------------------------------------|
| Irradiation doses (D) | PH SD NBS NFB NF NGF                  |
| Growth samplings (S)  | * * * * * *                           |
| D × S                 | * * * * * *                           |
| V. C. (%)             | 17 16 20 35 39 52                     |

Note: V. C. = Variation coefficient; PH = Plant height; SD = Stem diameter; NBS = Number of basal stems; NFB = Number of floral buds; NF = Number of flowers; NGF = Number of green fruits. * = Significant F test (p ≤ 0.05).

Figure 1. Growth dynamics of morphological and reproductive M₁ uchuva traits. Plant height (A), stem diameter (B), and number of basal stems (C), floral buds (D, flowers (E) and green fruits (F) through plant age (days after transplant). Each point corresponds to the average of 14 irradiation doses applied to the seed.
To our knowledge, this is the first report in which plant traits are measured throughout most part of the crop cycle to evaluate the averaged effect of the application of artificial mutagens. Generally, as for Solanaceae species are concerned, data is recorded in a single phenological stage, most of the times at flowering (López-Mendoza et al., 2012) or at harvest (Álvarez et al., 2013).

**Irradiation doses effects**

The effect of irradiation doses did not follow a linear response for any of the uchuva traits ($R^2$ from 0.50* to 0.80*) (Figure 2). $M_1$ plants whose seeds were exposed to low or high doses of radiation generally showed lower values than $M_1$ plants from seeds irradiated with intermediate doses. For breeding purposes, the most agronomical favorable doses were 125, 150, 175 and 200 Gy, since they produced $M_1$ plants of smaller plant height, with greater numbers of basal stems, floral buds, flowers and green fruits than plants from non-irradiated seeds (Figure 2). The earliest $M_1$ plants flowered at 53 dat (dose of 200 Gy) almost one week earlier than the control. In terms of yield components, $M_1$ plants from seeds irradiated at intermediate doses produced twice the amount of floral buds, flowers and green fruits than those from the non-irradiated seeds (Figure 2). These results are encouraging since one of the purposes of our uchuva breeding program is to select for early flowering and high yielding genotypes.

When a wide range of irradiation doses are applied, the response of plants to irradiation doses is not always linear (Yamaguchi et al., 2008; Canul-Ku et al., 2012); in addition, diploid organisms are more susceptible than polyploid organisms (Chopra, 2005). Regarding results in uchuva studies, Raghava and Raghava (1989) and Caro-Melgarejo et al. (2012) also observed that intermediate doses (100 to 200 Gy) favored the growth of $M_1$ plants of uchuva while doses higher than 200 Gy negatively affected plant growth. In other Solanaceae species, Aladjadjiyan (2007) mentioned that $M_1$ plants of tomato (*Solanum lycopersicum* L.) from seeds irradiated with X-rays (10 Gy) increased by 25% the stem thickness, and he demonstrated that the radiation stimulus depends on the wavelength, source of irradiation and exposure time. López-Mendoza et al. (2012) indicated that the flowering and fructification of the $M_1$ plants from irradiated seeds of *C. annuum* L. at doses of 0 to 120 Gy, occurred in a period similar to the control. They also mentioned that at the dose of 60 Gy the $M_1$ plants showed more fruits than the control. On the other hand, doses between 5 and 20 Gy increased by 66 and 72% the number of fruits per plant of *C. annuum* L., but doses higher than 130 Gy decreased it (Álvarez et al., 2013).

**Irradiation doses × Growth samplings interaction**

Several factors influence crop responses to irradiation treatments. These factors include: the source of radiation, irradiation dose and exposure time (De Souza et al., 2006); the irradiated organ (Orahola-Gómez et al., 2001; Caro-Melgarejo et al., 2012; Álvarez et al., 2013); the water content of the irradiated material (Ramírez et al., 2006); and the agronomic trait as well as the phenological stage in which measurements are taken. In the present study, the irradiation doses × growth samplings interaction was significant for all traits (Table 1). This means that the effect of the radiation is expressed in a particular way according to the plant age (*i.e.* the phenological stage represented by each sampling date) and the irradiation dose. Therefore, there is an optimal irradiation dose for each morphological and reproductive trait.

In the present study, this interaction is illustrated with the traits most closely related to the fruit yield of uchuva: *i.e.* the number of basal stems and that of reproductive traits (flowers and green fruits) at contrasting phenological growth stages (Figure 3). On average of the 14-irradiation doses there were 4.7 basal stems per plant at 46 dat and 6.3 at 121 dat (Figure 1). However, the interaction growth sampling × irradiation doses indicates that at 46 dat, plants from irradiated seeds with doses of 0 and 50 Gy had four basal stems while those from doses of 125, 175 and 200 Gy had six basal stems. In contrast, at 121 dat, plants from 200 Gy produced nine basal stems, significantly higher than those obtained in all irradiated plants at any other dose (Figure 3A).
The advantage on the number of flowers and green fruits produced by the M₁ plants from seeds irradiated with 200 Gy was more evident in the last sampling than in previous samplings (Figure 3B, 3C).

![Figure 2](image)

**Figure 2.** Irradiation doses response on morphological and reproductive of M₁ uchuva traits. Plant height (A; n = 7), stem diameter (B; n = 7), number of basal stems (C; n = 7), floral buds (D; n = 5), flowers (E; n = 5) and green fruits (F; n = 4). Each point represents the average of n growth samplings.

Finally, the application of 60Co gamma rays to seeds induces random changes in the DNA, which in most cases are recessive (Prina *et al*., 2011), so the expression of the induced mutations should be detected in the second generation (M₂), when recessive mutations are in homozygous condition. However, phenotypic changes can be detected in M₁ individuals as result of physiological effects of radiation (Kodym *et al*., 2011), although in a low frequency. In order to observe these specific changes for genetic improvement purposes, it can be appropriate to evaluate each M₁ individual of the irradiated population (Maluszynski *et al*., 2009), particularly when the crop, as the uchuva species, is suitable for vegetative propagation by crafting techniques. Therefore, although selection of early-maturity and high-yielding uchuva mutants will be performed in M₂ plants, vegetative propagation of outstanding M₁ plants is underway.
Figure 3. Examples of growth samplings × gamma-ray dose interaction for the number of basal stems (A), flowers (B) and green fruits (C) of M₁ uchuva plants. Bars with different small letter for each growth sampling (days after transplant) denote significant differences (Tukey, p ≤ 0.05)
Conclusions

The application of $^{60}$Co gamma rays (doses from 5 to 275 Gy) to seeds of Physalis peruviana L. reduce M₁ plants size. The stem diameter and the number of basal stems, floral buds, flowers and green fruits per plant increase during the growth cycle. The application of intermediate doses of gamma rays (125, 150, 175 and 200 Gy) stimulate vegetative growth and fruiting traits on M₁ uchuva plants, particularly at the dose of 200 Gy.

Acknowledgements

The authors gratefully acknowledge the scholarship granted to the first author by the National Council of Science and Technology of México (CONACYT).

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Ahloowalia, BS, Maluszynski M (2001). Induced mutations - A new paradigm in plant breeding. Euphytica 118:167-173. doi: https://doi.org/10.1023/A:1004162323428

Aladjadyan A (2007). The use of physical methods for plant growing stimulation in Bulgaria. Journal of Central European Agriculture 8:369-380.

Álvarez FA, Chávez SL, Ramírez FR, Estrada PW, Estrada LY, Maldonado RA (2013). Efecto del tratamiento de semillas con bajas dosis de rayos X en plantas de pimiento (Capsicum annuum L.). [Effect of seed treatment low doses of X-rays in peppers plants (Capsicum annuum L.)]. Nucleus 53:14-18.

Baek MH, Kim JH, Chung BY, Kim JS, Lee IS (2005). Alleviation of salt stress by low dose γ-irradiation in rice. Biologia Plantarum 49:273-276. doi: 10.1007/s10535-005-3276-3

Canul-Ku J, García-Pérez F, Campos-Bravo E, Barrios-Gómez EF, de la Cruz-Torres E, García-Andrade JM, Osuna-Canizalez FJ, Ramírez-Rojas S (2012). Efecto de la irradiación sobre nochebuena silvestre (Euphorbia pulcherrima Willd. ex Klotzsch) en Morelos. [Effect of irradiation on wild poinsettia (Euphorbia pulcherrima Willd. ex Klotzsch) in Morelos]. Revista Mexicana de Ciencias Agrícolas 3:1495-1507. https://doi.org/10.29312/remexca.v3i8.1316

Caro-Melgarejo DP, Estupiñán-Rincón SY, Rache-Cardenal LY, Pacheco-Maldonado JC (2012). Effect of gamma rays on vegetative buds of Physalis peruviana L. Acta Agronómica 61:305-314. doi: 305-314 2323-0118 0120-2812

Chakravarty B, Sen S (2001). Enhancement of regeneration potential and variability by y-g-irradiation in cultured cells of Scilla indica. Biologia Plantarum 44:189-193. https://doi.org/10.1023/A:1010282805522

Chopra VL (2005). Mutagenesis: Investigating the process and processing the outcome for crop improvement. Current Science 89:353-359. doi:www.jstor.org/stable/24110583

De Souza A, García D, Suero L, Gilart F, Porras E, Licea L (2006). Pre-sowing magnetic treatments of tomato seeds increase the growth and yield of plants. Biodectromagnetics 27:247-257. doi: 10.1002/bem.20206

Fischer G. (2000). Crecimiento y desarrollo. In: Flórez RVJ, Fischer G, Sora RAD (Eds). Producción, poscosecha y exportación de la uchuva (Physalis peruviana L.). Universidad Nacional de Colombia, Bogotá, Colombia pp 9-26.

Fischer G, Herrera A, Almanza PJ (2011). Cape gooseberry (Physalis peruviana L.). In: Yahia EM (Ed). Postharvest biology and technology of tropical and subtropical fruits. Volume 2. Acai to Citrus. Woodhead Publishing. Cambridge, UK pp 374-396.
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. [Radiation gamma effect on the differentiation of plants of sugar cane obtained from callus]. Agronomía Tropical 52: 311-323. http://scielo.isciii.es/scielo.php?script=sci_arttext&pid=S0002-192X2002000300004

Gastelum-Osorio DA, Sandoval-Villa M, Trejo-Libia C, Castro-Brindis R (2013). Fuerza iónica de la solución nutritiva y densidad de plantación sobre la producción y calidad de frutos de Physalis peruviana L. [Ionic strength of the nutrient solution and plant density on production and quality of Physalis peruviana L. fruits]. Revista Chapingo Serie Horticultura 19:197-210. doi: 10.5154/r.rchsh.2012.01.002

Gutiérrez-Castorena MC, Hernández Escobar J, Ortiz Solorio CA, Anicua Sánchez R, Hernández Lara ME (2011). Relación porosidad–retención de humedad en mezclas de sustratos y su efecto sobre variables respuesta en plántulas de lechuga. [Porosity–water retention relationship in substrate mixtures and its effect on response variables in lettuce seedlings]. Revista Chapingo Serie Horticultura 17:183-196.

Honda I, Kikuchi K, Matsuo S, Fukuda M, Saito H, Ryuho H, Fukunishi N, Abe T (2006). Heavyion-induced mutants in sweet pepper isolated by M1 plant selection. Euphytica 152: 61-66. https://link.springer.com/article/10.1007%2Fs10681-006-9177-5

Kim JH, Chung BY, Kim JS, Wi SG (2005). Effects of in Planta gamma-irradiation on growth, photosynthesis, and antioxidative capacity of red pepper (Capsicum annuum L) plants. Journal Plant Biology 48:47-56. https://link.springer.com/article/10.1007%2FBF03030564

Kim JH, Baek MH, Chung BY, Kim JS (2004). Alterations in the photosynthetic pigments and antioxidant machineries of red pepper (Capsicum annuum L) seedlings from gamma-irradiated seeds. Journal Plant Biology 47: 314-321. https://link.springer.com/article/10.1007/BF03030546

Kodym A, Afza R, Forster BP, Ukai Y, Nakagawa H, Miba C (2011). Methodology for physical and chemical mutagenic treatments. In: Shu QY, Forster BP, Nakagawa H (Eds). Plant mutation and biotechnology, Plant Breeding and Genetics Section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria pp 169-180.

Lagos BTC, Vallejo CFA, Criollo EH, Muñoz FJE (2008). Biología reproductiva de la uchuva [Sexual reproduction of the cape gooseberry]. Acta Agrónómica 57: 81-87. doi: 10.15446/acag

López-Mendoza H, Carrillo-Rodríguez JC, Chávez-Servia JL (2012). Effects of gamma-irradiated seeds on germination and growth in Capsicum annuum L plants growth in a greenhouse. Acta Horticulturae 947: 77-81. doi: 10.17660 /ActaHortic.2012.947.7

Malszynski M, Szarejko I, Bhatia CR, Nichterlein K, Lagoda PJL (2009). Methodologies for generating variability. Part 4: Mutation techniques. In: Ceccarelli S, Guimarães EP, Weltzien E (Eds). Plant breeding and farmer participation. Food and Agriculture Organization of the United Nations. Rome, Italy pp 159-194.

Matsumura A, Nomizu T, Funatani N, Hayashi K, Minamiyama Y, Hase Y (2010). Ray florets color and shape mutants induced by 12C5+ ion beam irradiation in chrysanthemum. Scientia Horticulturae 123:558-561. https://dx.doi.org/10.1016/j.scienta.2009.11.004

Mohan Jain S (2006). Mutation-assisted breeding for improving ornamental plants. Acta Horticulturae 714: 85-98. doi: 10.17660 /ActaHortic.2006.714.10

Otalora-Gómez V, Aray M, Antoima Y (2001). Inducción de mutantes para el color de la flor en crisantemos (Dendranthema grandiflora (Ram) Tzvelev) mediante radiaciones gamma. [Induction of mutants in flower color of chrysanthemum (Dendranthema grandiflora (Ram) Tzvelev) using gamma irradiation]. Revista UDO Agrícola 1:56-63.

Prina AR, Landau AM, Pacheco MG (2011). Chimeras and mutant gene transmission. In: Shu QY, Forster BP, Nakagawa H (Eds). Plant mutation and biotechnology, plant breeding and genetics section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria pp 181-190.

Raghava RP, Raghava N (1989). Effects of gamma irradiation on fresh and dry weights of plant parts in Physalis L. Geobios 16: 261-264.
Ramírez R, González LM, Camejo Y, Zaldívar N, Fernández Y (2006). Estudio de radiosensibilidad y selección del rango de dosis estimulantes de rayos X en cuatro variedades de tomate (*Lycopersicum esculentum* L.). [Radiation sensitivity study and selection of the range of irradiation stimulation doses of X-rays in four tomato cultivars]. Cultivos Tropicales 27:63-67.

http://www.redalyc.org/articulo.oa?id=193215885012

Rodríguez E, Rockenbach II, Cataneo C, Gonzaga I.V, Chaves ES, Fett R (2009). Minerals and essential fatty acids of the exotic fruit *Physalis peruviana* L. Ciência e Tecnologia de Alimentos 29: 642-645. doi: 10.1590/S0101-206120090003000029

Santana G, Angarita A (1997). Regeneración adventicia de somoclonales de Uchuva (*Physalis peruviana* L.). Agronomía Colombiana 14:59-65.

SAS, Institute. 2004. SAS/STAT User’s Guide. Version 9.1. SAS Institute. Cary, NC, USA.

Wu DL, Hou SW, Qian PP, Sun LD, Zhang YC, Li WJ (2009). Flower color chimera and abnormal leaf mutants induced by 12C6⁺ heavy ions in *Salvia splendens* Ker-Gawl. Scientia Horticulturae 121:462-467. doi: 10.1016/j.scienta.2009.02.022

Yamaguchi H, Shimizu A, Degi K, Morishita T (2008). Effects of dose and dose rate of gamma ray irradiation on mutation induction and nuclear DNA content in chrysanthemum. Breeding Science 58: 331-335. doi: 10.1270/jsbbs.58.331

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