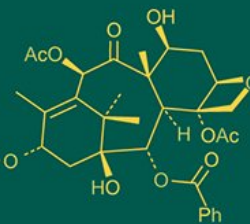
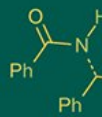


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(7): 1494-1500
www.biochemjournal.com
Received: 26-04-2026
Accepted: 04-06-2026

Vrushali D Chougale
Ph.D. Scholar, Department of Fruit
Science, Dr. Panjabrao Deshmukh
Krishi Vidyapeeth (Dr. PDKV),
Akola, Maharashtra, India

SR Patil
Professor, Department of Fruit
Science, Dr. Panjabrao Deshmukh
Krishi Vidyapeeth (Dr. PDKV),
Akola, Maharashtra, India

DM Panchbhavi
Director of Instruction and Dean,
Faculty of Agriculture, Dr.
Panjabrao Deshmukh Krishi
Vidyapeeth (Dr. PDKV), Akola,
Maharashtra, India

VU Raut
Professor, Horticulture Section,
College of Agriculture, Nagpur, Dr.
Panjabrao Deshmukh Krishi
Vidyapeeth (Dr. PDKV), Nagpur,
Maharashtra, India

Ekta P Ningot
Assistant Professor, Horticulture
Section, College of Agriculture,
Nagpur, Dr. Panjabrao Deshmukh
Krishi Vidyapeeth (Dr. PDKV),
Nagpur, Maharashtra, India

RD Walke
Associate Professor, Department of
Agricultural Economics and
Statistics, Dr. Panjabrao
Deshmukh Krishi Vidyapeeth (Dr.
PDKV), Akola, Maharashtra, India

MS Janbandhu
Ph.D. Scholar, Department of Fruit
Science, Dr. Panjabrao Deshmukh
Krishi Vidyapeeth (Dr. PDKV),
Akola, Maharashtra, India

VN Patil
Assistant Professor (Horticulture),
Bhausaheb Fundkar Government
College of Agriculture, Buldhana,
Dr. Panjabrao Deshmukh Krishi
Vidyapeeth (Dr. PDKV),
Buldhana, Maharashtra, India

Corresponding Author:
Vrushali D Chougale
Ph.D. Scholar, Department of Fruit
Science, Dr. Panjabrao Deshmukh
Krishi Vidyapeeth (Dr. PDKV),
Akola, Maharashtra, India

Effect of gamma irradiation on growth parameters of mutated mandarin orange (*Citrus Reticulata* Blanco)

Vrushali D Chougale, SR Patil, DM Panchbhavi, VU Raut, Ekta P Ningot, RD Walke, MS Janbandhu and VN Patil

DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i7Sr.9253>

Abstract

The present investigation entitled “Effect of Gamma Irradiation on Growth Parameters of Mutated Mandarin Orange (*Citrus reticulata* Blanco)” was carried out at the Futala farm, Horticulture Section, College of Agriculture, Nagpur during 2022-23, 2023-24 and 2024-25. The experiment was laid out in Randomized Block Design with eleven treatments and replicated thrice. Total 500 budsticks treatment⁻¹ of Nagpur mandarin and Nagpur seedless were treated with 10, 20, 30, 40, 50 Gy doses of gamma irradiation. After gamma irradiation treatment, the budsticks of Nagpur mandarin and Nagpur seedless were budded on rough lemon rootstock planted in polythene bags of size 8-12 inch. Once the budded plants attained sufficient growth and after final survival they were hardened and subsequently transplanted to the open field for morphological characterization. The observations recorded were growth parameters like plant height, Branches plant⁻¹, number of leaves, leaf length and leaf width in M₁ generation.

The results revealed that gamma irradiation significantly influenced all vegetative growth parameters in a dose-dependent manner. The growth parameters like plant height, leaf length and leaf width were significantly reduced after radiation with increase in exposure of gamma rays. At 32 MAP, the maximum plant height, leaf length, leaf width was recorded in Nagpur mandarin (control) (246.79 cm, 6.31 cm, 5.19 cm), while the minimum was observed in Nagpur seedless treated with 50 Gy (91.82 cm, 5.10 cm and 3.40 cm). In contrast, branching behaviour increased substantially under moderate irradiation doses, with the maximum number of branches recorded in Nagpur seedless treated with 40 Gy (22.67 branches plant⁻¹ at 6 MAP). Lower irradiation doses (10-20 Gy) maintained vegetative growth comparatively close to untreated controls. number of leaves plant⁻¹ showed irregular trend.

Keywords: *Citrus reticulata*, gamma irradiation, mutation breeding, plant height, leaf length, leaf width, number of leaves plant⁻¹, number of branches plant⁻¹

Introduction

The genus *Citrus* is one of the most economically important fruit crops in the world, widely cultivated for its nutritious juice, edible pulp, and commercially valuable by-products. It belongs to the sub-tribe Citrineae, sub-family Aurantioideae and family Rutaceae and comprises 162 species according to Tanaka's classification. Citrus crops are widely grown in tropical and subtropical regions of the world and occupy a prominent position in global fruit production. Citrus is cultivated in about 137 countries, and global citrus production reached 166.30 million tonnes during 2023. China, Brazil, and India are the leading citrus-producing countries, contributing 48.77, 19.73, and 14.76 million tonnes, respectively. Among citrus fruits, sweet orange accounts for the largest share of global production (45.95%), followed by mandarins, tangerines, and clementines (26.57%), lemons and limes (12.95%), pummelo and grapefruit (5.87%), and other citrus fruits (8.67%). (Kamatyanatt *et al.*, 2021) [8].

India ranks as the third largest producer of citrus fruits globally, following China and Brazil. Other major citrus producing countries include Spain, United States, Israel, Morocco, South Africa, Japan, Turkey and Cuba. Among the various citrus fruits cultivated in India, mandarins lead in both area and production followed by sweet oranges and limes. In the 2023-24 season, mandarin cultivation covered approximately 4.74 lakh hectares and yielding around 60.75 lakh metric tonnes (Anonymous, 2024). The leading mandarin growing states in India are Maharashtra, Andhra Pradesh, Punjab, Karnataka, Orissa, Bihar, Assam, Tamil Nadu and Gujarat. Maharashtra is one of the leading citrus producing states of India, where

mandarin and sweet orange constitute a major share of the citrus area and production. The total production of mandarin in Maharashtra 1342.78 thousand MT from an area of 143.72 thousand hectares with a productivity of 9.34 MT ha⁻¹ (Anonymous, 2024). Within Maharashtra, the Vidarbha region, particularly the districts of Nagpur and Amravati forms the principal mandarin belt, where Nagpur mandarin is predominantly cultivated.

Inducing mutations by gamma-rays has been effectively used in several species of citrus. Irradiation of budwood with gamma rays can produce higher frequencies of mutation, leading to the creation of new variants compared to the parent variety. Gamma irradiation based mutagenesis of budwood has been the most commonly used method by citrus breeders worldwide to obtain seedless clones from commercial seeded varieties of orange, mandarin, grapefruit and lemon. An alternative method to obtain seedless citrus fruit is through breeding of triploid trees. Physical mutagens induce gross lesions, such as chromosomal abbreviation or rearrangements. It is noteworthy that the frequency and types of mutations are direct results of the dosage and rate of exposure or administration of the mutagen rather than its type (Mba *et al.*, 2012) [12]. In India, mutagenesis studies have been taken up for acid lime, sweet orange and mandarins and the resulting plants are in the initial stages of valuation. Considering the commercial importance of Nagpur mandarin and the growing need for genetically improved planting material, the present investigation was undertaken to evaluate the effect of different doses of gamma irradiation on growth parameters of mutated Nagpur mandarin and Nagpur seedless under field conditions. The study aimed to study the effect of gamma rays on plant height, leaf length, leaf width, number of leaves and branching behaviour.

Materials and Methods

Experimental Site

The present investigation was conducted during the years

2022-23, 2023-24 and 2024-25 at Futala Farm, Horticulture Section, College of Agriculture, Nagpur, under Dr. Panjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola, Maharashtra, India. The experimental site is situated in the subtropical climatic region of central India and falls within the Vidarbha agro-climatic zone, which is characterized by hot summers, mild winters and monsoon-dominated rainfall patterns. The region experiences an average annual rainfall of approximately 1000-1200 mm, most of which is received during the southwest monsoon season. The soil of the experimental field was well-drained and suitable for citrus cultivation.

Plant material

Two mandarin varieties, namely Nagpur mandarin and Nagpur seedless (*Citrus reticulata* Blanco.) belonging to the family Rutaceae, were used as experimental material for the study. Healthy and uniform bud stick of both varieties were selected and utilized for mutation induction treatments. After gamma irradiation treatment, the bud sticks of Nagpur mandarin and Nagpur seedless were budded on rough lemon rootstock planted in polythene bags of size 8-12 inch. Once the budded plants attained sufficient growth (approximately 30 to 45 cm in height), they were hardened and subsequently transplanted to the open field to carry out systematic data recording on key morphological parameters, including plant height, leaf length, leaf width, number of leaves plant⁻¹ and number of branches plant⁻¹.

Gamma irradiation treatment

The budstick of both mandarin genotypes were subjected to gamma irradiation using a Cobalt-60 (Co-60) gamma radiation source prior to planting. Five different doses of gamma rays, viz., 10, 20, 30, 40 and 50 Gy, were employed to induce mutagenic variability. Untreated cuttings of both genotypes served as controls.

Treatment details

Table 1: Gamma Irradiation Treatments in Nagpur Mandarin and Nagpur Seedless

T ₁	Nagpur mandarin + No irradiation (Control)
T ₂	Nagpur mandarin + 10 Gy Gamma rays
T ₃	Nagpur mandarin + 20 Gy Gamma rays
T ₄	Nagpur mandarin + 30 Gy Gamma rays
T ₅	Nagpur mandarin + 40 Gy Gamma rays
T ₆	Nagpur seedless + No irradiation (control)
T ₇	Nagpur seedless + 10 Gy Gamma rays
T ₈	Nagpur seedless + 20 Gy Gamma rays
T ₉	Nagpur seedless + 30 Gy Gamma rays
T ₁₀	Nagpur seedless + 40 Gy Gamma rays
T ₁₁	Nagpur seedless + 50 Gy Gamma rays

The experiment was laid out in a Randomized Block Design (RBD) comprising eleven treatments with three replications. All irradiated and control plants were planted under uniform field conditions and maintained using standard cultural practices recommended for mandarin cultivation.

Observations recorded

To evaluate the effect of gamma irradiation on vegetative growth behaviour, observations on plant height, leaf length, leaf width, number of leaves plant⁻¹ and number of branches plant⁻¹ were recorded periodically over the experimental duration.

1. Plant height (cm)

Plant height was measured from the ground level to the apical growing point using a measuring scale and expressed in centimetres. Observations were recorded at 4 month intervals from 4 months after planting (MAP) up to 32 MAP.

2. Leaf length (cm)

Length of leaf was measured with measuring scale at an interval of 4 month after planting upto 32 month after planting. The length of leaf was measured from the base of the petiole to the tip of the leaf and was expressed in centimeter (cm).

3. Leaf width (cm)

Leaf width was measured at the center of leaf with measuring scale at an interval of 4 month after planting upto 32 month after planting. The width of the leaf was expressed in centimeter (cm)

4. Number of leaves plant⁻¹

Average number of leaves per plant of bud grafts was recorded at an interval of 2 month after planting.

5. Number of branches plant⁻¹

The number of branches plant⁻¹ was recorded as cumulative counts of primary, secondary and tertiary branches. Primary branches were counted at 2 MAP, primary and secondary branches at 4 MAP and cumulative primary, secondary and tertiary branches at 6 MAP.

Statistical analysis

The experimental data generated during the course of investigation were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for Randomized Block Design as described by Panse and Sukhatme (1985) [13]. The significance of treatment effects was tested using the F-test at 5 per cent probability level. Whenever treatment differences were found significant, the Critical Difference (CD) at 5% level of significance was calculated for comparison of treatment means. Standard Error of Mean [S.E.(m)±] values were also computed for all recorded observations. The observed responses were interpreted on the basis of dose-dependent effects of gamma irradiation on vegetative growth and branching behaviour of the mandarin genotypes under field conditions.

Result and discussion

Effect of gamma irradiation on growth parameters of mutated mandarin orange (*Citrus reticulata* Blanco.)

The effect of different doses of gamma irradiation on

vegetative growth parameters of mutated Nagpur mandarin and Nagpur seedless was evaluated under field conditions over a period extending from 2 to 32 months after planting (MAP). The observations recorded on plant height, leaf length, leaf width, number of leaves plant⁻¹ and number of branches plant⁻¹ revealed significant variations among treatments at different growth stages, indicating a pronounced influence of gamma irradiation on vegetative development and canopy architecture of mandarin orange.

Effect of Gamma Irradiation on Plant Height

The data pertaining to plant height are presented in Table 1 and depicted in Fig 1. The plant height of Nagpur Mandarin (NM) mutants was significantly influenced by various gamma radiation doses across all growth stages (4 to 32 MAP).

Among Nagpur mandarin mutants, at 4,16,20 and 32 MAP, Control (T₁) recorded significantly maximum plant height of (58.83,147.67,165.33 and 246.79 cm, respectively), which was at par with NM + 10 Gy (T₂) (58.72, 138.44,161.70 and 243.74 cm, respectively) and NM + 20 Gy (T₃) (57.68, 136.54,156.81 and 237.43 cm, respectively) and NM+30 GY (54.15,134.11,156.50 and 234.68 cm, respectively).

At 8,12 and 24 MAP, the significantly maximum plant height was recorded by NM + 10 GY (T₂) (89.73,117.33 and 183.55 cm, respectively) which was at par with control (T₁) (88.53, 116.38 and 179.81 cm, respectively), NM +20 GY (87.04, 112.72 and 177.69 cm respectively) and NM + 30 GY (83.50, 110.79 and 171.70 cm, respectively)

At 28 MAP significant maximum plant height was recorded by control (T₁) (207.54 cm) which was at par with NM + 10 GY (207.41 cm). However, the minimum plant height was consistently observed in NM + 40 Gy (T₅) (48.50, 72.83, 101.40, 129.58, 142.33, 159.17, 181.69 and 229.67 cm, respectively) across all growth stages from 4 to 32 MAP.

Table 2: Effect of gamma radiation doses on plant height (cm) of Mandarin mutants

Treatments		4 MAP	8 MAP	12 MAP	16 MAP	20 MAP	24 MAP	28 MAP	32 MAP
NM (Control)	T ₁	58.83	88.53	116.38	147.67	165.33	179.81	207.54	246.79
NM + 10 Gy	T ₂	58.72	89.73	117.33	138.44	161.70	183.55	207.41	243.74
NM + 20 Gy	T ₃	57.68	87.04	112.72	136.54	156.81	177.69	197.39	237.43
NM + 30 Gy	T ₄	54.15	83.50	110.79	134.11	156.50	171.70	195.17	234.68
NM + 40 Gy	T ₅	48.50	72.83	101.40	129.58	142.33	159.17	181.69	229.67
NS (Control)	T ₆	55.17	88.50	117.30	143.00	156.09	184.20	203.06	241.89
NS + 10 Gy	T ₇	48.82	75.69	110.97	135.53	159.66	178.66	202.82	239.64
NS + 20 Gy	T ₈	47.98	75.34	105.43	135.35	155.90	177.17	200.18	225.85
NS + 30 Gy	T ₉	46.03	71.42	99.19	129.42	147.74	165.83	183.96	217.02
NS + 40 Gy	T ₁₀	32.20	60.00	80.87	126.33	144.83	163.18	183.25	202.51
NS + 50 Gy	T ₁₁	36.33	52.47	65.44	69.36	84.47	87.70	88.05	91.82
Range		32.20-58.83	52.47-89.73	65.44-117.33	69.36-147.67	84.47-165.33	87.70-184.20	88.05-207.54	91.82-246.79
General Mean		49.49	76.82	103.43	129.57	148.90	166.24	186.41	219.18
F-Test		Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
S.E. (m)±		2.97	4.39	6.06	5.37	3.93	4.80	2.75	5.39
CD at 5%		6.82	13.05	18.00	15.96	11.69	14.28	8.18	16.01

Among Nagpur Seedless (NS) mutants, at 4,8 and 32 MAP the significantly maximum plant height was shown by NS control (T₆) (55.17, 88.50, 241.89 cm, respectively) which was at par with NS + 10 GY (T₇) (48.82, 75.69 and 239.64 cm, respectively).

At 12, 24 and 28 MAP, the significantly more plant height was observed in NS (control) (T₆) (117.30,184.20 and 203.06 cm, respectively) which was at par with NS + 10 GY

(T₂) (110.97,178.66 and 202.82 cm, respectively) and NS +20 GY (T₈) (105.43, 177.17 and 200.18 cm, respectively)

At 16 MAP, the maximum plant height was exhibited by NS (control) (T₆) (143.00 cm) which was at par with NS + 10 GY (135.53 cm, respectively).

At 20 MAP, the maximum plant height was recorded by NS + 10 GY (159.66 cm) which was at par with NS (Control) and NS + 20 GY (156.09, 155.90 cm) and the minimum plant height was consistently recorded in NS + 50 Gy (T₁₁),

with values of 52.47, 65.44, 69.36, 84.47, 87.70, 88.05, and 91.82 cm from 8 to 32 MAP, respectively except at 4 MAP minimum plant height was recorded in NS + 40 Gy (T₁₀) (32.20 cm).

The plant height recorded at different stages of plant growth indicated a progressive reduction with an increase in the doses of gamma rays. Gamma irradiation may cause destruction or damage to apical meristems or partial failure of the internodes to elongate so as to result in decreased number of proliferating cells. (Chatse, 2023)

A similar line of research work had been documented by Saini and Gill (2009) ^[15] in rough lemon, Kumar *et al.*, (2023) ^[10] in Kinnow mandarin, Singh *et al.*, (2018) ^[17] in Guava, Manjusha *et al.*, (2024) ^[11] in Acid lime, Ghasemi-Soloklui *et al.*, (2025) ^[6] in Fig, Srikanth *et al.*, (2026) ^[18] in Litchi. Brar and Bal (2003) ^[4] in Guava, Kaur and Rattanpal (2008) in rough lemon, Sharafi *et al.*, (2013) ^[16] in almond.

Effect of gamma radiation doses on leaf length of mandarin mutant.

The data regarding leaf length presented in Table 2. Data in table revealed that the leaf length of Nagpur Mandarin (NM) mutants showed significant variation in response to different gamma irradiation doses throughout the study period (4 to 32 MAP).

Among Nagpur mandarin mutants, at 4, 16, 28 and 32 MAP, the significantly maximum leaf length was exhibited by NM (Control) (T₁) (5.25, 5.82, 6.17 and 6.31 cm, respectively) which was at par with NM + 10 Gy (T₂) (4.51, 5.76, 5.95 and 6.21 cm, respectively).

At 8 and 12 MAP the significantly maximum leaf length was exhibited by NM (Control) (T₁) (5.38 and 5.48 cm, respectively) which was at par with NM + 10 Gy (T₂) (4.98

and 5.38 cm, respectively) and NM + 20 Gy (T₃) (4.58 and 5.03 cm, respectively). At 20 MAP, the significantly maximum leaf length was exhibited by NM + 10 Gy (T₂) (6.03 cm), which was at par with NM (Control) (T₁) (5.80 cm) and NM + 20 Gy (T₃) (5.29 cm). At 24 MAP, the significantly maximum leaf length was exhibited by NM + 10 Gy (T₂) (6.10 cm), which was at par with NM (Control) (T₁) (5.87 cm). While consistently minimum leaf length was observed in treatment NM + 40 Gy (T₅) (3.58, 3.82, 4.23, 4.38, 4.42, 4.43, 4.99 and 5.29 cm, respectively) across all growth stages from 4 to 32 MAP. Among Nagpur Seedless (NS) mutants, at 8, 12, 20, 24 and 28 MAP, the Control (T₆) recorded a maximum leaf length of (5.27, 5.28, 5.86 and 5.91 cm, respectively), which was at par with NS + 10 Gy (T₇) (5.07, 5.22, 5.76 5.80 and 5.84 cm, respectively) and NS + 20 Gy (T₈) (4.56, 4.97, 5.14, 5.34 and 5.44 cm, respectively). At 4, 16 and 32 MAP, maximum leaf length was observed in NS (control) (T₆) (4.85, 6.02 and 6.17 cm, respectively), which was at par with NS + 10 Gy (T₇) (4.47, 5.75 and 5.93 cm respectively). While, NS + 50 Gy (T₁₁) recorded the lowest leaf length throughout all stages of growth, with values of 2.70, 3.53, 3.95, 4.50, 4.76, 4.77, 4.97, and 5.10 cm from 4 to 32 MAP. The reduction in leaf length of gamma irradiated plants might be due to the chromosomal damage and inhibition of mitotic activity of cells which brought down the rate of cell division resulting into poor growth of leaves. The results of the present investigation are supported by the findings of Taheri *et al.*, (2016) in *Curcuma alismatifolia*, Surakshitha *et al.*, (2017) ^[19] in grape, Rattanpal *et al.*, (2019) ^[14] in Mandarin, Ghasemi-Soloklui *et al.*, (2025) ^[6] in fig who noticed the significant reduction in leaf length after radiation as compared to the control.

Table 3: Effect of gamma radiation doses on leaf length (cm) of Mandarin mutant

Treatments		4 MAP	8 MAP	12 MAP	16 MAP	20 MAP	24 MAP	28 MAP	32 MAP
NM (Control)	T ₁	5.25	5.38	5.48	5.82	5.80	5.87	6.17	6.31
NM + 10 Gy	T ₂	4.51	4.98	5.38	5.76	6.03	6.10	5.95	6.21
NM + 20 Gy	T ₃	4.00	4.58	5.03	5.06	5.29	5.32	5.48	5.98
NM + 30 Gy	T ₄	3.89	4.11	4.54	4.90	4.92	5.02	5.13	5.51
NM + 40 Gy	T ₅	3.58	3.82	4.23	4.38	4.42	4.43	4.99	5.29
NS (Control)	T ₆	4.85	5.27	5.28	6.02	5.86	5.91	5.98	6.17
NS + 10 Gy	T ₇	4.47	5.07	5.22	5.75	5.76	5.80	5.84	5.93
NS + 20 Gy	T ₈	3.84	4.56	4.97	5.10	5.14	5.34	5.44	5.85
NS + 30 Gy	T ₉	3.79	3.93	4.50	4.84	4.95	5.20	5.22	5.37
NS + 40 Gy	T ₁₀	3.67	3.90	4.07	4.73	4.77	5.17	5.20	5.32
NS + 50 Gy	T ₁₁	2.70	3.53	3.95	4.50	4.76	4.77	4.97	5.10
Range		2.70-5.25	3.53-5.38	3.95-5.48	4.50-6.02	4.76-6.03	4.77-6.10	4.97-6.17	5.10-6.31
General Mean		4.05	4.46	4.78	5.16	5.24	5.35	5.48	5.73
F-Test		Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
S.E. (m)±		0.25	0.27	0.24	0.23	0.26	0.20	0.21	0.10
CD at 5%		0.74	0.81	0.72	0.68	0.78	0.59	0.64	0.29

Effect of gamma radiation doses on leaf width of mandarin mutant

The analysis of data on leaf width is presented in Table 3. Leaf length of both Nagpur Mandarin (NM) and Nagpur seedless mutants showed significant variation in response to different gamma irradiation doses across all growth stages (4 to 32 MAP).

Among the Nagpur mandarin mutants, at 4 MAP, NM + 10 Gy (T₂) recorded the maximum leaf width (2.31 cm), which was at par with Control (T₁) (2.28 cm), NM + 20 Gy (T₃) (2.27 cm) and NM + 30 Gy (T₄) (2.19 cm) At 8 MAP, NM + 10 Gy (T₂) also recorded the maximum leaf width (2.42 cm)

which was at par with Control (T₁) (2.39 cm) and NM + 20 Gy (T₃) (2.28 cm). At 12 MAP, NM + 10 Gy (T₂) recorded the maximum leaf width (2.56 cm), which was at par with Control (T₁) (2.43 cm). At 16 and 28 MAP, maximum leaf width was observed in NM (control) (2.78, 3.26 cm) which was at par with NM + 10 Gy (2.62, 3.03 cm, respectively). At 20, 24 and 32 MAP, maximum leaf width was recorded in NM (control) (2.83, 2.99 and 5.19 cm, respectively), which was at par with NM + 10 Gy (T₂) (2.79, 2.83 and 5.11 cm, respectively) and NM + 20 Gy (T₃) (2.63, 2.79 and 4.76 cm, respectively). While the minimum leaf width was observed in NM + 40 Gy (T₅) (1.74, 1.84, 1.94, 2.38, 2.52,

2.60, 2.61 and 3.60 cm) from 4 to 32 MAP, respectively. Among the Nagpur Seedless mutants, at 4, 28 and 32 MAP, maximum leaf width was observed in NS (control) (T₆) (2.34, 3.13 and 4.91 cm, respectively) which was at par with NS + 10 Gy (T₇) (2.25, 3.01 and 4.79 cm, respectively), NS + 20 Gy (T₈) (2.17, 2.93 and 4.60 cm, respectively) and NS + 30 Gy (T₉) (2.03, 2.86 and 4.55 cm, respectively). While NS + 50 Gy (T₁₁) recorded consistently minimum leaf width, with values of 1.74, 2.01, 2.09, 2.38, 2.46, and 3.40 cm from 12 to 32 MAP, respectively, except at 4 and 8 MAP,

minimum width was observed in NS + 40 Gy (T₁₀) (1.66 and 1.70 cm, respectively). The reductions in leaf width at higher doses can be linked to oxidative stress and disrupted hormonal regulation caused by gamma radiation. These findings are consistent with the research of Taheri *et al.*, (2016) in *Curcuma alismatifolia*, Surakshitha *et al.*, (2017) [19] in grape, Rattanpal *et al.*, (2019) [14] in Mandarin, Ghasemi- Soloklu *et al.*, (2025) [6] in fig who reported that a gradual decrease in leaf width was observed with higher irradiation doses.

Table 4: Effect of gamma radiation doses on leaf width (cm) of Mandarin mutant

Treatments		4 MAP	8 MAP	12 MAP	16 MAP	20 MAP	24 MAP	28 MAP	32 MAP
NM (Control)	T ₁	2.28	2.39	2.43	2.78	2.83	2.99	3.26	5.19
NM + 10 Gy	T ₂	2.31	2.42	2.56	2.62	2.79	2.83	3.03	5.11
NM + 20 Gy	T ₃	2.27	2.28	2.33	2.54	2.63	2.79	2.84	4.76
NM + 30 Gy	T ₄	2.19	2.23	2.21	2.41	2.59	2.61	2.66	3.88
NM + 40 Gy	T ₅	1.74	1.84	1.94	2.38	2.52	2.60	2.61	3.60
NS (Control)	T ₆	2.34	2.40	2.49	2.53	2.74	2.93	3.13	4.91
NS + 10 Gy	T ₇	2.25	2.34	2.31	2.44	2.62	2.81	3.01	4.79
NS + 20 Gy	T ₈	2.17	2.18	2.24	2.39	2.58	2.64	2.93	4.60
NS + 30 Gy	T ₉	2.03	2.11	2.14	2.24	2.43	2.55	2.86	4.55
NS + 40 Gy	T ₁₀	1.66	1.70	1.91	2.12	2.19	2.43	2.58	3.47
NS + 50 Gy	T ₁₁	1.69	1.76	1.74	2.01	2.09	2.38	2.46	3.40
Range		1.66-2.34	1.70-2.42	1.74-2.56	2.01-2.78	2.09-2.83	2.38-2.99	2.46-3.26	3.40-5.19
General Mean		2.08	2.15	2.20	2.40	2.54	2.64	2.79	4.38
F-Test		Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
S.E. (m)±		0.16	0.06	0.06	0.07	0.06	0.08	0.12	0.23
CD at 5%		0.49	0.17	0.19	0.21	0.20	0.24	0.37	0.70

Effect of gamma radiation doses on number of leaves plant⁻¹ of mandarin mutant.

The data pertaining to the number of leaves presented in Table 4. Indicated that non-significant differences among all the treatments at all three growth stages in M₁ generation. Among Nagpur mandarin mutants, at 2 and 3 MAP, numerically maximum number of leaves was observed in NM + 30 Gy (T₄) (36.56 and 66.85), while minimum number of leaves observed in NM + 40 Gy (T₅) (27.08 and 57.41). At 4 MAP, numerically maximum number of leaves observed in NM + 20 Gy (T₃) (125.67), while minimum number of leaves observed in NM + 40 Gy (T₅) (107.67). Among Nagpur seedless mutants, at 2 and 3 MAP,

numerically maximum number of leaves was observed in NS + 30 Gy (T₉) (36.33 and 66.44), while minimum number of leaves observed in NS + 40 Gy (T₁₀) (25.78 and 55.78).

At 4 MAP, numerically maximum number of leaves observed in NS (control) (124.67), while minimum number of leaves observed in NS + 50 Gy (T₁₁) (80.33). The data suggesting that gamma irradiation did not follow any definite pattern in influencing leaf number.

These results were agreement with the findings of Abdulhafiz *et al.*, (2018) [1] in banana and Jyoti *et al.*, (2026) [7] in mandarin who reported that gamma irradiation had no significant impact on leaf number, however no clear mutation trend was observed in irradiated treatments.

Table 5: Effect of gamma radiation doses on number of leaves plant⁻¹ of Mandarin mutant

Treatments		2 MAP	3 MAP	4 MAP
NM (Control)	T ₁	34.66	64.51	119.67
NM + 10 Gy	T ₂	32.66	62.85	121.33
NM + 20 Gy	T ₃	34.33	64.74	125.67
NM + 30 Gy	T ₄	36.56	66.85	115.33
NM + 40 Gy	T ₅	27.08	57.41	107.67
NS (Control)	T ₆	31.87	61.79	124.67
NS + 10 Gy	T ₇	31.53	61.13	116.67
NS + 20 Gy	T ₈	33.90	63.12	115.33
NS + 30 Gy	T ₉	36.33	66.44	88.00
NS + 40 Gy	T ₁₀	25.78	55.78	87.10
NS + 50 Gy	T ₁₁	34.01	64.50	80.33
Range		25.78-36.56	55.78-66.85	80.33-125.67
General Mean		32.61	62.64	109.25
F-Test		NS	NS	NS
S.E. (m)±		2.33	2.36	11.29
CD at 5%		6.99	7.08	33.87

Effect of gamma radiation doses on number of branches plant⁻¹ of mandarin mutants

Data regarding number of branches plant⁻¹ as influenced by different irradiation doses are presented in Table 5. From the

table, it is found that the gamma radiation dose significantly influenced on number of branches plant⁻¹ at all growth stages.

Among Nagpur mandarin mutants, at 2 months after planting, the maximum number of primary branches (6.17) was observed in NM + 40 Gy (T₅) followed by NM + 30 Gy (T₄) (5.12) while the minimum number of primary branches was observed in NM (Control) (T₁) (3.17).

At 4 months after planting, maximum number of primary and secondary branches was observed in NM + 40 Gy (T₅) (18.00) which was at par with NM + 30 Gy (T₄) (17.20), while minimum number of primary, secondary branches was recorded by NM (control) (10.56).

At 6 MAP, maximum number of primary, secondary and tertiary branches was observed in NM + 40 Gy (T₅) (22.50) followed by NM + 30 Gy (21.03), while minimum number of primary, secondary and tertiary branches was recorded by NM (control) (16.79). Among Nagpur seedless mutants, at 2 months after planting, the maximum number of primary branches (6.33) was observed in NS + 40 Gy (T₁₀) which was at par with NS + 50 Gy (T₁₁) (5.90), while the minimum number of primary branches was observed in NS (Control) (T₆) (3.19). At 4 months after planting, maximum number of primary and secondary branches was observed in NS + 40 Gy (T₁₀) (18.67) followed by NS + 30 Gy (T₉) (17.17),

while minimum number of primary and secondary branches was recorded by NS (control) (T₆) (13.90). At 6 MAP, maximum number of primary, secondary and tertiary branches was observed in NS + 40 Gy (T₁₀) (22.67) followed by NM + 30 Gy (T₉) (21.07), while minimum number of primary, secondary and tertiary branches was recorded by NS (control) (18.73). Radiation treatments probably induced some changes at the gene level that ultimately reflected in substances that trigger biochemical processes controlling different aspects of growth. These substances, identified as auxins, gibberellins, ethylene and abscisic acid called phytohormones, initiates biochemical reactions and induce changes in chemical patterns that lead to various modifications and variations in plant characters, viz., height, branching and stem thickness, as mentioned in Saini and Gill (2009) [15]. These results are close findings with Brar and Bal (2003) [4], Singh *et al.*, (2018) [17] in guava, Saini and Gill (2009) [15] in rough lemon and Jyoti *et al.*, (2026) [7] in mandarin who reported that number of branches per plant increased with increase in gamma irradiation doses.

Table 6: Effect of gamma radiation doses on number of branches plant⁻¹ of Mandarin mutant

Treatments		2 MAP (Primary)	4 MAP (Primary + Secondary)	6 MAP (P + S + Tertiary)
NM (Control)	T ₁	3.17	10.56	16.79
NM + 10 Gy	T ₂	3.32	15.03	19.40
NM + 20 Gy	T ₃	4.73	16.07	20.03
NM + 30 Gy	T ₄	5.12	17.20	21.03
NM + 40 Gy	T ₅	6.17	18.00	22.50
NS (Control)	T ₆	3.19	13.90	18.73
NS + 10 Gy	T ₇	3.20	15.00	19.43
NS + 20 Gy	T ₈	4.68	16.10	20.10
NS + 30 Gy	T ₉	5.03	17.17	21.07
NS + 40 Gy	T ₁₀	6.33	18.67	22.67
NS + 50 Gy	T ₁₁	5.90	11.50	17.53
Range		3.17-6.33	10.56-18.67	16.79-22.67
General Mean		4.62	15.38	19.93
F-Test		Sig	Sig	Sig
S.E. (m)±		0.28	0.27	0.30
CD at 5%		0.85	0.81	0.90

Conclusion

The present investigation demonstrated that gamma irradiation significantly influenced the vegetative growth behaviour of Nagpur mandarin and Nagpur seedless in a dose-dependent manner under field conditions. Increasing doses of gamma rays progressively reduced plant height, leaf length, leaf width whereas branching behaviour increased up to moderate irradiation levels before declining at the highest dose. However, number of leaves showed in irregular trend. Gamma irradiation does not disrupt the fundamental rhythm of leaf initiation. Lower doses of 10 Gy and 20 Gy maintained vegetative growth comparatively close to untreated controls, indicating their biological suitability for mutation breeding programmes, while higher doses, particularly 40 Gy and 50 Gy, caused severe suppression of growth parameters. Overall, the findings indicate that gamma irradiation can serve as an effective tool for inducing useful morphological variability in citrus, and irradiation doses between 10 and 20 Gy may be considered optimal for generating agronomically viable mutant lines for future citrus improvement programmes.

References

1. Abdulhafiz F, Kayat F, Zakaria S. Effect of gamma irradiation on the morphological and physiological variation from *in vitro* individual shoot of banana cv. Tanduk (*Musa* spp.). J Plant Biotechnol. 2018;45(2):140-145.
2. Anonymous. Ministry of Agriculture and Farmers Welfare database. New Delhi: Ministry of Agriculture and Farmers Welfare; 2024.
3. Anonymous. *Horticultural Statistics at a Glance*. Gurgaon: National Horticultural Board; 2024.
4. Brar HS, Bal JS. Studies on the use of gamma rays on the performance of guava buddings. Ann Agri Bio Res. 2003;8(2):213-218.
5. Chatase DB. *Mutation studies in bougainvillea* [thesis]. Akola: Dr. Panjabrao Deshmukh Krishi Vidyapeeth; 2023.
6. Ghasemi-Soloklui AA, Kordrostami M, Jafari M. Determination of optimal gamma radiation dose for mutation breeding in 'Sabz' fig (*Ficus carica* L.)

- cuttings based on radiosensitivity and phenotypic changes. PLoS One. 2025;20(1): e0313017.
7. Jyoti, Ningot EP, Panchbhai DM, Gajbhiye RP. Impact of gamma irradiation on growth parameters and variability in mandarin orange. Plant Arch. 2026; 26:1746-1756.
 8. Kamatyanatt M, Shailesh KS, Bhallan SS. Mutation breeding in citrus - A review. Plant Cell Biotechnol Mol Biol. 2021:1-8.
 9. Kaur S, Rattanpal HS. Effect of mutagens on *in vitro* seed germination and growth of rough lemon (*Citrus jambhiri*) seedlings. Indian J Agric Sci. 2010;80(9):773-773.
 10. Kumar S, Awasthi O, Pandey R, Dubey AK, Sharma RM. Production performance and fruit quality of gamma-irradiated mutants of 'Kinnow' mandarin (*Citrus nobilis* Loureiro × *Citrus deliciosa* Tenora). Erwerbs-Obstbau. 2023; 65:379-387.
 11. Manjusha MR, Rajangam J, Saraswathy S, Venkatesan K, Rajesh S, Madhan MM, Ganasekaran M. Effect of gamma rays induced mutagenesis on the agronomical and biochemical traits of acid lime. Plant Sci. 2024.
 12. Mba C, Afza R, Shu QY. Mutagenic radiations: X-rays, ionizing particles and ultraviolet. In: Shu QY, Forster BP, Nakagawa H, editors. *Plant Mutation Breeding and Biotechnology*. Wallingford: CABI; 2012. p. 83-90.
 13. Panse VG, Sukhatme PV. *Statistical Methods for Agricultural Workers*. New Delhi: Indian Council of Agricultural Research; 1958. p. 84-85.
 14. Rattanpal HS, Gurteg S, Gupta M. Studies on mutation breeding in mandarin variety Kinnow. Curr Sci. 2019;116(3).
 15. Saini HK, Gill MIS. Induction of mutation in rough lemon (*Citrus jambhiri* Lush.) using gamma rays. J Hortic Sci. 2009;4(1):41-44.
 16. Sharafi Y, Rezaei A, Ghanbari A, Naji AM. Gamma irradiation affected phenotypic characteristics of almond (*Prunus amygdalus* L.). Int J Agron Plant Prod. 2013;4(1):25-29.
 17. Singh S, Gill MIS, Arora NK. Induction of variants in guava (*Psidium guajava* L.) through irradiation of budsticks by gamma rays. Agric Res J. 2018;55(2):347-350.
 18. Srikanth N, Kumar S, Das B, Kumar A, Samal I, Limbalkar OM, Dhakad A. Gamma radiation induced genetic variability and physiological modulation in mutant litchi (*Litchi chinensis* Sonn.) population. Cogent Food Agric. 2026;12(1):2610024.
 19. Surakshitha NC, Soorianathasundaram K, Ganesan NM. Determination of mutagenic sensitivity of hardwood cuttings of grapes 'Red Globe' and 'Muscat' (*Vitis vinifera* L.) to gamma rays. Sci Hortic. 2017; 226:152-156.
 20. Taheri S, Abdullah TL, Ahmad Z, Abdullah NAP. Effect of acute gamma irradiation on *Curcuma alismatifolia* varieties and detection of DNA polymorphism through SSR marker. Biomed Res Int. 2014; 2014:631813.