Persian J. Acarol., 15(3): 150311.

https://www.persianacarology.org
Research Article
https://biotaxa.org/pja
https://doi.org/10.22073/pja.150311

Gamma irradiation as an alternative treatment for controlling the population growth of *Tetranychus urticae* (Acari: Tetranychidae) on fruit tree leaves in the laboratory

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Received:
20 December, 2025
Accepted:
10 July, 2026
Published:
15 July, 2026
Subject Editor:
P. Lotfollahi

ABSTRACT

The application of non-chemical disinfestation treatment for managing the *Tetranychus urticae* mite pest was investigated in the laboratory. Gamma-ray irradiation at 0, 100, 200, 300, and 400 Gy was applied to eggs, immature stages, and adults of *T. urticae* on guava leaves (*Psidium guajava*). Irradiation of eggs resulted in failed hatchability, eggs' viability at 100 and 200 Gy was partially reduced and was highly suppressed (7.59%) at 400 Gy. The effect of gamma radiation on mite biological parameters was analyzed using ANOVA. Gamma rays at 300 and 400 Gy caused growth retardation in irradiated nymphs and delayed the emergence of the subsequent developmental stage; this growth delay is likely a physiological response to cellular damage. Mites may redirect energy from rapid development toward DNA repair mechanisms. The longevity of irradiated females was substantially shortened ($p < 0.05$) by increasing radiation dose rates. At lower doses, the total number of eggs deposited by treated females was greatly decreased, and at 400 Gy, it was highly suppressed. Mites exposed to 300–400 Gy resulted in a significant reduction in fecundity ($p < 0.05$). When irradiated males and unirradiated females mated, the majority of the resulting progeny (F1 adults) were males. Based on the results, irradiation with a dose of 400 Gy can be an effective sterilization treatment for *T. urticae* on guava leaves. Our study explored gamma rays as an environmentally friendly technique for controlling two-spotted spider mites. A sterilization dose of 400 Gy, derived from our laboratory study, can be applied subsequently to adult males (*T. urticae*) on guava leaves. These sterilized males can then be released into the field to mate with wild females, thereby reducing pest populations over time. This method could use gamma rays for field-level pest control.

KEYWORDS

Egg hatchability, Ionizing radiation, longevity, sterility, two-spotted spider mite

CITE: Farid, H.M. & Sayed, R.M. (2026) Gamma irradiation as an alternative treatment for controlling the population growth of *Tetranychus urticae* (Acari: Tetranychidae) on fruit tree leaves in the laboratory. *Persian Journal of Acarology*, 15(3): 150311.
https://doi.org/10.22073/pja.150311

INTRODUCTION

In Egypt, the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae) is among the most harmful mite pests of many agricultural products, including fruit trees. In greenhouses, it attacks more than 300 plant species (Sandeep *et al.* 2024). Common symptoms include yellowish patches on the upper leaf surface, a typical sign of chlorophyll loss. Severe injury caused by this pest may lead to leaf scorching, defoliation, or even plant death. The two-spotted spider mite has five developmental stages: egg, larva, protonymph, deutonymph, and adult. Development from egg to adult often takes two to three weeks, depending on temperature, host plant, humidity, and other environmental factors. Male development is faster than that of females; unfertilized eggs only yield haploid males, while fertilized eggs produce diploid females (Zhang 2003; Sandeep *et al.* 2024). All countries are concerned about plant pests that could be detrimental to agricultural systems, especially with the increasing international trade in agricultural products. To prevent the introduction of dangerous pests into new areas, control techniques are applied to disinfect commodities before export. The continuous use of synthetic acaricides has become less effective against the mites due to rapid resistance development, and it also destroys the natural enemies (Bergeron and Schmidt-Jeffris 2021; Safar and Mohamed 2024).

In the context of Egyptian agriculture and pest management research, the guava tree *Psidium guajava* (Myrtaceae) is a high-priority crop infested with *T. urticae* (Elhalawany and Abou-Setta 2013). Guava leaves provide an ideal microclimate and nutrient profile for spider mites. Mites in Egyptian guava orchards have developed high resistance to traditional chemical acaricides. Some studies have addressed the geographical distributions of pesticide residues in guava fruits grown in three main Egyptian governorates. Significant contamination and a variety of farming methods across the regions were shown by the identification of 24 different chemical substances. The study concludes that heavy pesticide use in Egyptian guavas results in a dangerous residue mixture (Badawy *et al.* 2023). On the other hand, the continuous use of synthetic acaricides is less effective against mites due to rapid resistance development and the destruction of natural enemies (Bergeron and Schmidt-Jeffris 2021; Safar and Mohamed 2024).

A significant portion of the Arab Republic of Egypt's overall exports are agricultural products. Some studies focused on the quality of Egyptian agricultural exports, which is essential to their growth in overseas markets. The problem of declining quality in Egyptian agricultural exports surfaced as severe international standards and requirements were implemented to ensure the security and safety of imports from other nations (Alesawy *et al.* 2023).

Ionizing radiation techniques are increasingly being used to control pest species infecting agricultural products (Osakabe 2021). For many agricultural products, irradiation might be a useful alternative technique (Mshelia *et al.* 2023). Irradiation is considered a suitable quarantine treatment due to its eco-friendly use in IPM programs within greenhouses (Abd El-Ghfar *et al.* 2025). In certain regions of the world, ionizing radiation is also used to control harmful pest populations. Advantages include not retaining toxic residues and having a shorter treatment time than fumigation (Yuan and Osakabe 2019; Osakabe 2021). Ionizing radiation penetrates commodities quickly and deeply, without altering their temperature (Follett 2009). The irradiation technique does not directly cause mortality, but rather works by breaking chemical bonds in DNA, which can lead to growth retardation or sterility in the organism (Yun *et al.* 2014; Osakabe 2021). Since all stages of insect pests are typically found on the infected plant, it is crucial to study the response of each developmental stage to radiation.

The current study investigated the effects of different gamma radiation rates (100, 200, 300, and 400 Gy) as a non-chemical technology for the management of *T. urticae* on guava leaves (*P. guajava*), in the laboratory. The effects of different gamma radiation rates on the activity of *T. urticae* developmental stages are recorded. The optimal sterilizing dose derived from a laboratory study can be applied later by using sterilized males for field-level pest control, thereby reducing the pest population over time.

MATERIAL AND METHODS

Mite rearing

The susceptible strain of the two-spotted spider*, T. urticae,* was obtained from a colony maintained in the Acarology laboratory, Plant Protection Research Institute, and had never been exposed to any acaricides. Mass culture of mites was reared in the laboratory according to the methods described by Awad *et al.* (2018). Successful cultures of the susceptible strain of *T. urticae* require a strictly controlled climate, incubated at 25 ± 2 °C and 60% ± 5% relative humidity to ensure rapid generation times, and are maintained in special chambers to prevent contamination or the introduction of predators.

- Mass rearing by introducing the infested leaf of the host plant onto fresh plants; the mites will naturally migrate to the healthy ones.

- To prevent escape, place infested leaf discs on water-saturated cotton pads in Petri dishes. The water acts as a physical barrier that the mites cannot cross. deteriorates, turning yellow; heavily damaged plants are removed every 7–10 days to maintain high population vigor and prevent mold buildup.

Mites were transferred using a fine camel hairbrush onto fresh guava leaves placed on moistened cotton in (12 cm diameter) Peri dishes. To obtain similar-aged adults for irradiation, 0–12-hour-old eggs were incubated at 25 ± 2 °C, 60% ± 5% relative humidity, and a 16L:8D photoperiod.

Irradiation with gamma rays

Mites were exposed to radiation at the National Center for Radiation Research and Technology (NCRRT), Egyptian Atomic Energy Authority, Cairo, Egypt. During testing, *T. urticae* eggs, nymphs, and adults were irradiated with 100, 200, 300, and 400 Gy. These doses were selected according to the recommendations of the International Atomic Energy Agency (IAEA) (1992) and Hallman (2016). Higher doses (500+ Gy) may cause phytotoxicity, damaging the color or cellular structure of the fruit product.

Mites were placed in a glass Petri dish with a lid. The unit has ventilation holes that align with ventilation parts through the main shield, providing a means for uniform irradiation of each sample. The samples were subjected to γ-radiation to various doses using a ^{60}Co Gamma Cell (GC-220 Excel, manufactured by MDS Nordion, Canada) with a dose rate of 0.584 kGy/h for 10 minutes per dose. This cell was calibrated with alanine pellet dosimeters provided by the National Physical Laboratory, NPL, UK (traceability to NPL).

To evaluate the effect of gamma rates on *T. urticae* eggs, 20 mature females were transferred to a guava leaf-disc (2 cm diameter) using a camel hairbrush on a damp cotton pad in a Petri dish (12 cm diameter). Females were left to lay eggs for 24 hours and then removed. The one-day-old eggs were irradiated, immediately returned to the laboratory, and placed in Petri dishes in an incubator at 25 ± 2 °C and 60% ± 5% relative humidity. Eggs were examined for hatchability over a five-day period. The eggs that did not hatch after this time were considered non-viable. The experiment was replicated four times for each dose level and control.

Immature stages were irradiated, and 20 larvae, 20 protonymphs, and 20 deutonymphs were transferred to separate Petri dishes containing a guava leaf cut (2 cm in diameter), as described above, to observe their growth and emergence rates. The experiment was replicated four times for each dose level and control

To evaluate the effect of gamma radiation on biological parameters of adult females, 24-hour-old females were transferred to a guava leaf cut and exposed to each of the gamma doses to assess longevity, fecundity (total number of eggs laid), and egg hatchability. Adult mortality was recorded one day post-irradiation.

Fertility of adult mites was studied as 10 untreated males with each radiation dose were transferred and reproduced with ten treated adult females on tested guava leaf-cuts; 10 treated males reproduced with 10 untreated adult females; ten treated males reproduced with 10 treated adult females. All experiments were replicated four times.

Data analysis

A randomized complete block design was used in the present study. Percentage hatchability data were arcsine-square-root-transformed prior to analysis to ensure normality. Additionally, all ANOVA assumptions, including normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test), were verified and met. The data were analyzed using a one-way analysis of variance (ANOVA) to investigate the effect of gamma radiation on the biological parameters of mites using the dose-response data for eggs and adults. The comparison between treatments was conducted by Tukey's HSD. Statistical analyses were performed using IBM SPSS Statistics 31.0.0.0 software.

RESULTS

Effect of irradiation rates on T. urticae *eggs*

Increasing the gamma radiation dose significantly reduced the hatchability of *T. urticae* eggs ($p < 0.05$), as shown in Table 1. Compared with the control treatment (94.53%), egg viability decreased to 73.18% at 100 Gy. Egg viability was drastically reduced to 14.71% and 7.59% at 300 and 400 Gy, respectively.

Table 1. Mean hatchability of *Tetranychus urticae* eggs exposed to different irradiation rates.

Gamma rate (Gy)	No. of eggs treated	No. of eggs hatched	Mean hatchability (%)	Statistics
Control	166	157	94.53 ± 10.42 a	P = 0.000
100	150	109	73.18 ± 7.32 b	F = 142.27
200	131	59	44.87 ± 4.33 c	
300	157	23	14.71 ± 2.82 d	
400	144	11	7.59 ± 2.39 d	

Values in the same column followed by different letters are substantially different by Tukey's HSD test at p = 0.05. The results represent the mean ± S.D. of four replicate leaf discs.

Effect of irradiation rates on T. urticae females

Exposure of adult *T. urticae* females to gamma radiation showed that none of the applied doses caused mortality in adults one day post-irradiation. The mean longevity of irradiated females decreased significantly ($p < 0.05$) with increasing radiation dose (Table 2). The longevity of females irradiated at 100 Gy decreased to (13.5 ± 1.29) days compared to (16.25 ± 1.7) days in the control group. At 400 Gy, mean longevity decreased sharply to 2.25 ± 0.96 days.

Gamma radiation significantly affected the fecundity of irradiated females ($p < 0.05$), as determined by ANOVA (Table 2). A significant reduction in egg deposition was observed at 400 Gy, with a mean of 47 ± 2 eggs per female. The hatchability of eggs laid by irradiated females decreased with increasing radiation dose ($p < 0.05$).

The hatching rate of eggs deposited by irradiated mites at 100 and 200 Gy decreased to 73.5% and 66.25%, respectively, compared to 92.75% in the control. Hatchability was drastically reduced to 31.75% and 15.25% at 300 and 400 Gy, respectively. As a result, these dosage rates cause severe impairment of fertility and a significant reduction in reproductive capacity.

Table 2. Mean longevity of *T. urticae* females exposed to different irradiation rates on guava leaves.

Irradiation rate (Gy)	Mean longevity of irradiated females	Deposited eggs	Hatchability (%)
Control	16.25 ± 1.7 a	1570± 1.7 a	92.75 ± 2.21 a
100	13.50 ± 1.29 b	141 ± 1.5 b	73.50 ± 2.64 b
200	10.25 ± 1.25 c	125 ± 2.75 c	66.25 ± 5.18 c
300	5.50 ± 1.29 d	103 ± 3.9 d	31.75 ± 3.3 d
400	2.25 ± 0.96 e	47 ± 2.5 e	15.25 ± 2.04 e
P value	0.000 ***	0.000 ***	0.000 ***

Values in the same column followed by different letters are substantially different by Tukey's HSD test at p = 0.05. The results represent the mean of four replication leaf discs ± S.D.

Effect of irradiation rates on immature stages

Table 3 shows the effect of gamma radiation on the immature stages of *T. urticae*. The proportion of adults that emerged from irradiated immatures tended to significantly decline as the radiation rate increased. Larvae were more susceptible to radiation than protonymphs and deutonymphs.

Effect of treated adults with irradiation on their fertility

Microscopic observation of the experiment showed decreased activity and slow movement of mites after irradiation. Table 4 shows a reduction in egg deposition at lower doses when untreated males mated with irradiated females. Compared with the control (91.75%), egg viability decreased to 68.75% and 58.75% at 100 and 200 Gy, respectively.

Table 3. Mean emergence rate of *Tetranychus urticae* immatures irradiated by different doses of gamma rays.

Irradiation rate (Gy)	Larva	Protonymph	Deutonymph
Control	90.50 ± 1.29 a	92.75 ± 2.21 a	91.5 ± 2.64 a
100	68.50 ± 0.57 b	75.25 ± 1.26 b	88.25 ± 1.26 b
200	65.75 ± 0.95 c	73.50 ± 1.29 b	84.5 ± 1.73b
300	36.25 ± 1.26 d	62.75 ± 3.86 c	76.5 ± 2.64 c
400	25.25 ± 1.25 e	56.25 ± 0.5 d	64.75 ± 1.5 d
P value	0.0000 ***	0.0000 ***	0.0000 ***

Values in the same column followed by different letters are substantially different by Tukey's HSD test at p = 0.05. The results represent the mean of four replication discs ± S.D.

The tested gamma doses significantly affected egg laying ($p < 0.05$), inducing female sterility, with effects increasing at higher doses compared to the control. The irradiation rate of 400 Gy resulted in a significantly reduced number of laid eggs (39.5 ± 4.8%) and severely suppressed hatchability rate (11 ± 2.44%).

When irradiated males mated with untreated females, most of the resulting progeny (F1 adults) were males, due to parthenogenesis. At 300 Gy, the progeny consisted mostly of males, with a ratio of 71.34 to 47.76 females. The resulting male numbers increased with increasing irradiation rate; at 400 Gy, female numbers are highly suppressed (21.38) compared with male numbers (86.23). The progeny's sex ratio was thoroughly assessed using a Chi-square test. Males were more common in the raw data, and the statistical analysis shows that this difference is significant ($\chi^2 = 88.72$, $p < 0.00001$).

When both sexes were irradiated, fecundity and egg viability decreased with increasing radiation dose, reaching 4.25% at 400 Gy compared to 92.75% in the control.

Table 4. Fertility of adults *T. urticae* after treatment with different rates of gamma radiation on guava leaf discs.

Irradiation rates (Gy)	Untreated male × Treated female		Treated male × Untreated female		No. of emerged		Treated male × Treated female	
	Deposited eggs	Egg viability (%)	Deposited eggs	Egg viability (%)	Females	Males	Deposited eggs	Egg viability (%)
Control	170.7 ± 3.9a	91.7 ± 2.7 a	161.0 ± 6.72a	94.2 ± 3.8a	82.26	22.74	146.7 ± 3.6a	92.8 ± 1.9a
100	131.0 ± 4.8 b	68.8 ± 7.4 b	140.8 ± 3.3bc	91.5 ± 2.4 a	78.61	42.18	105.5 ± 5.2b	55.8 ± 4.4b
200	112.5 ± 8.8 c	58.7 ± 3.5 c	135.7 ± 3.7 c	87.2 ± 7.3 b	61.24	52.67	86.8 ± 4.6c	42.3 ± 4.1c
300	86.2 ± 6.6 d	28.5 ± 2.1 d	143.8 ± 6.6b	81.5 ± 3.7 bc	47.76	71.34	64.5 ± 4.2d	16.5 ± 2.6 c
400	39.5 ± 4.8 e	11.0 ± 2.4 e	155.5 ± 4.2a	76.2 ±5.1 c	21.38	86.23	34.8 ± 7.4e	4.3 ± 2.2 d
P value	0.000 ***	0.000 ***	0.000 ***	0.0005 ***	$\chi^2 = 88.72$	$p < 0.00001$	0.000 ***	0.000 ***

Data are the mean of four replicate discs ± S.D. Values in the same column followed by different letters are significantly different by Tukey's HSD test at p = 0.05.

DISCUSSION

Our results confirm that gamma radiation acts as a potent suppressor of *T. urticae* biological aspects, specifically targeting longevity, fecundity, and fertility. Mean hatchability of *T. urticae* eggs was considerably reduced ($p < 0.05$) by increasing the dose rate of irradiation. These results are in accordance with those of Osouli *et al.* (2013), Kim *et al.* (2015) and Abd El-Ghfar *et al.* (2025).

We identified 300–400 Gy as the critical threshold for developmental arrest. This is quantitatively higher than the 200 Gy reported by Koo *et al.* (2021) for initial hatching inhibition yet aligns with their findings that 400 Gy is necessary for total reproductive cessation. This discrepancy suggests that while lower doses may trigger physiological stress, a minimum of 400 Gy is required to ensure complete population control.

Furthermore, our observation that 300–400 Gy resulted in highly male progeny (when treated males mated with untreated females) provides a clear mechanism for population collapse when applied in the field. This 'male-only' outcome corroborates the results of Sulaiman *et al.* (2004) and, compared with Osouli *et al.* (2014), who achieved sterility at 320 Gy, our data suggest a slightly broader effective range, perhaps due to different host plants or temperatures.

Radiation significantly extended the developmental duration of immature *T. urticae* stages, a phenomenon that aligns with Hallman (2011). This growth delay is likely a physiological response to cellular damage; the organism redirects energy from rapid development toward DNA repair mechanisms.

Our findings further substantiate the hypothesis that larvae and nymphs are more radiosensitive than adults. While adults can often withstand 400 Gy without immediate mortality, we observed that immature stages were significantly more vulnerable. Specifically, fewer adults emerged from treated nymphs in our study, mirroring the reduction in emergence noted by Sulaiman *et al.* (2004) in *Tetranychus piercei* McGregor. This high susceptibility in early life stages is due to the high rate of cell division (mitosis) during molting and growth, making immature mite tissues more prone to lethal ionizing radiation than the relatively stable tissues of the adult. Consequently, targeting the immature population may provide a more efficient path to total population suppression than focusing solely on adult eradication.

Our investigation identified a critical reproductive tipping point between 300 and 400 Gy, at which eggs deposited by irradiated females lost viability. This inhibition of hatching at 400 Gy represents a more severe reproductive impact than that observed by Osouli *et al.* (2014), while they reported that adults emerging from irradiated immatures at 350 Gy produced eggs with low hatchability.

Furthermore, we observed a dose-dependent decline in mite longevity, corroborating Hallman's (2011) findings. Quantitatively, our data showed a reduction in life span (2.25 days) at the highest dose (400 Gy) compared to the control. This shortened longevity, combined with reduced egg hatchability, creates a dual-action suppression of the population; it simultaneously shortens the feeding period and prevents the recruitment of new individuals. A potential limitation to consider is that while 400 Gy effectively halts the population, the decreased emerged adults may vary depending on the host plant's nutritional quality, which was not the focus of the current study.

Despite these clear trends, this study was limited to a single generation and a specific plant host under controlled laboratory conditions. Future research should assess whether sub-lethal doses trigger compensatory reproductive surges or whether efficacy remains consistent across different *T. urticae* strains.

Guava fruits are among the most important agricultural products exported worldwide, and mites in Egyptian guava orchards have developed high resistance to traditional chemical acaricides (Badawy *et al.* 2023). Direct application of gamma irradiation in open fields is not a standard practice and does not involve broadcasting radiation due to environmental safety. Instead, before harvesting, the technology is applied to pest control through the Sterile Pest Technique (SPT), a method that uses gamma irradiation for field-level pest control. Sterilization of two-spotted spider mites for field application involves two steps: mass-rearing the mites for irradiation and selecting a sterilizing dose based on a laboratory study. Then, control of the mite pest is achieved by releasing sterile adults into the field population. Unlike chemical pesticides, the radiation is applied only to the target pest before release, ensuring that natural enemies remain unaffected (Timbadiya *et al.* 2018). In the field, non-target insects may be shielded by soil, foliage, or different micro-habitats that attenuate radiation. There are no documented off-target effects on other insects.

CONCLUSION

According to the laboratory study, gamma irradiation suppressed the biological characteristics of *T. urticae*, resulting in decreased viability of deposited eggs, growth retardation of immature stages, and reduced longevity of irradiated females. We verified that gamma-ray irradiation can be used as a nonphytotoxic therapy against two-spotted spider mites on guava leaves at doses of 300-400 Gy, which causes high sterility in adults. Direct application of gamma irradiation in open fields is not a standard practice due to environmental safety. Our study determines 400 Gy as the optimal radiation dose required to sterilize adult male *T. urticae* on Guava leaves in the laboratory. Consequently, the process and mechanism could be carried out by large populations of males that are mass-reared in specialized labs and exposed to a precise dose of gamma radiation (from a laboratory study) to induce sterility without significantly harming their ability to mate. The sterile males are subsequently released into the field population. When the sterile males mate with wild females, no offspring are produced, thereby reducing the pest population over time.

ACKNOWLEDGEMENTS

We are deeply indebted to the Plant Protection Research Institute (ARC) for its continued support of our research. We also thank the National Center for Radiation Research and Technology (EAEA) for their efforts in gamma irradiation and all reviewers who contributed their time and effort to improve the manuscript.

Author contributions: Methodology: Sampling, collection, preparation and irradiation of specimens: H.F., R.S.; Analyses and data curation: H.F.; writing – original draft preparation: H.F.; writing – revisions and editing: H.F.; supervision: H.F., R.S. funding acquisition: H.F. All authors have read and agreed to the published version of the manuscript.

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Availability of data and materials: Data are available upon request from the authors.

Ethics approval and consent to participate: This study only included arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

Consent for publication: All study participants, or their legal guardian, provided informed written consent prior to study enrollment.

Competing interests: The authors declare no conflict of interest.

Generative AI statement: The authors declare that no use of Gen AI was made in the creation of this manuscript.

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تابش گاما به عنوان یک روش جایگزین برای کنترل رشد جمعیت *Tetranychus urticae* (Acari: Tetranychidae) روی برگ درختان میوه در آزمایشگاه

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دریافت

۲۹ آذر ۱۴۰۴

پذیرش

۱۹ تیر ۱۴۰۵

انتشار

۲۴ تیر ۱۴۰۵

دبیر تخصصی

پ. لطف‌الهی

چکیده

کاربرد روش‌های غیرشیمیایی ضدعفونی برای مدیریت آفت *Tetranychus urticae* در آزمایشگاه مورد مطالعه قرار گرفته است. تابش اشعه گاما در دوزهای ۰، ۱۰۰، ۲۰۰، ۳۰۰ و ۴۰۰ گری بر روی تخم‌ها، مراحل نابالغ و حشرات بالغ *T. urticae* روی برگ‌های گوآوا (*Psidium guajava*) اعمال شد. تابش اشعه گاما به تخم‌ها منجر به عدم موفقیت در تفریخ تخم‌ها، حتی در دوزهای کم شد. زنده‌مانی تخم‌ها در دوزهای ۱۰۰ و ۲۰۰ گری تا حدی کاهش یافت و در دوزهای ۴۰۰ گری به شدت (۷.۵۹٪) محدود شد. تأثیر تابش گاما بر پراسنجه‌های زیستی کنه با استفاده از آنالیز واریانس (ANOVA) تجزیه و تحلیل شد. پرتوهای گاما در دوزهای ۳۰۰ و ۴۰۰ گری باعث کاهش رشد در پوره‌های پرتو دیده و تأخیر در ظهور در مرحله رشد بعدی شدند. این تأخیر رشد به احتمال پاسخ فیزیولوژیکی به آسیب سلولی است. کنه‌ها انرژی را از رشد سریع به سمت سازوکارهای ترمیم DNA هدایت می‌کنند. با افزایش میزان دوز پرتو، طول عمر کنه‌های مادهٔ بالغ به میزان زیادی کوتاه شد ($p < 0.05$). در دوزهای کم‌تر، تعداد کل تخم‌های گذاشته شده توسط کنه‌های ماده تحت درمان به میزان زیادی کاهش یافت و در دوز ۴۰۰ گری، این تعداد به شدت محدود شد. کنه‌های قرار گرفته در معرض دوز ۳۰۰–۴۰۰ منجر به کاهش زیاد باروری شدند. هنگامی که کنه‌های نر تحت تابش و کنه‌های ماده تحت تابش جفت‌گیری کردند، بیشتر فرزندان حاصل (بالغ‌های F1) نر بودند. بر اساس نتایج، تابش با دوز ۴۰۰ گری می‌تواند روش عقیم‌سازی مؤثری برای کنهٔ تارتن دولکه‌ای (*T. urticae*) روی برگ‌های گوآوا باشد. این مطالعه پرتوهای گاما را به عنوان روشی سازگار با محیط زیست برای مهار کنه آفت تایید کرد. دوز عقیم‌سازی ۴۰۰ گری، که از این بررسی آزمایشگاهی به دست آمده است، می‌تواند برای کنه‌های نر بالغ *T. urticae* روی برگ‌های گوآوا اعمال شود. این نرهای عقیم‌شده سپس می‌توانند در مزرعه رها شوند تا با ماده‌های وحشی جفت‌گیری کنند و در نتیجه جمعیت آفات را به مرور زمان کاهش دهند. این روش می‌تواند پرتوهای گاما را برای مهار آفات در سطح مزرعه استفاده می‌کند.

واژگان کلیدی: قابلیت تفریخ تخم، تابش یونیزه کننده، طول عمر، عقیمی، کنه تارتن دو لکه‌ای

CITE: Farid, H.M. & Sayed, R.M. (2026) Gamma irradiation as an alternative treatment for controlling the population growth of *Tetranychus urticae* (Acari: Tetranychidae) on fruit tree leaves in the laboratory. *Persian Journal of Acarology*, 15(3): 150311.
https://doi.org/10.22073/pja.150311