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# GAMMA IRRADIATION AS A QUARANTINE TREATMENT FOR SPIDER MITES (*Acarina: tetranychidae*) IN HORTICULTURAL PRODUCTS

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**Abstract**

The carmine spider mite, *Tetranychus cinnabarinus* (Boisd.), and the two-spotted spider mite, *Tetranychus urticae* Koch, are closely related species of tetranychid mites *(Acarina, Tetranychidae)* that respond to gamma irradiation in a similar way. Eggs of both species exposed to gamma radiation early in embryonic development were considerably more susceptible to irradiation than older eggs. The tolerance of eggs to gamma radiation increased in 3-4-day-old eggs, when eye-spots were formed. Nymphs were more resistant to gamma radiation than eggs and larvae. Deteriorative effects of irradiation treatment were reflected in the immatures by their mortality in subsequent developmental stages. A positive relationship between dosage and the percent egg mortality or the mortality of subsequent stages was usually found when the immature stages were irradiated. The sex ratio of adults developed from irradiated eggs, larvae, and nymphs was affected by the irradiation treatment; the ratio was usually skewed towards males. Irradiation of females resulted in increased mortality, lowered fecundity, reduced egg viability, and sex ratio distortion in their progeny. Two-day-old females of the carmine spider mite and the two-spotted spider mite irradiated with 200 or 300 Gy lived as long as the controls. Mortality occurred after 3 weeks. The number of eggs laid by irradiated females of spider mites was considerably lower than in the control, and it decreased as the absorbed dose increased. The higher the dose of gamma radiation applied to adults of the spider mites (the parental generation, *P*), the higher the mortality of the *F1* mites during their embryonic development. Viability of eggs laid by irradiated females of spider mites mated with irradiated males was significantly reduced. Young females treated with a dose of 0.2 kGy produced 40-50% nonviable eggs, while control mites produced only 6.0-6.6% nonviable eggs. A dose of 0.3 kGy caused high mortality of eggs; 88% and 97% nonviable eggs were found for the carmine spider mite and the two-spotted spider mite, respectively. In general, viability of eggs produced by mites irradiated as young females and old females was similar. The higher the dose of gamma radiation applied to adults of the spider mites, the higher the mortality of offspring during their embryonic development. However, a dose of 0.3 kGy did not cause complete sterility. To determine a sterilizing dose for both sexes, spider mites were irradiated with the following doses: 0.3, 0.31, 0.32, 0.33, 0.34, 0.35, and 0.4 kGy. When mites were treated with 0.30 and 0.31 kGy, a few eggs hatched. Data obtained indicate that a dose of 0.32 kGy is the lowest dose causing complete sterility in the carmine spider mite and the two-spotted spider mite, when both males and females were irradiated. This dosage could be used for irradiation as a quarantine treatment of horticultural products infested with spider mites.

## 1. INTRODUCTION

Various spider mite species of the family *Tetranychidae* are notorious pests on several crops. The economic significance of spider mites as pest species has increased considerably during recent decades because of their great ability to develop resistance to a wide variety of pesticides. Until recently, chemical control of spider mites has not been a problem since a few very effective acaricides are still applicable. However, irradiation as a quarantine treatment will be the next alternative to chemical control of spider mites on cut flowers, vegetables and some fruits.

High doses (1-3 kGy) of ionizing radiation resulting in the immediate mortality of mite pests are not recommended as they cause phytotoxicity to horticultural produce. Lower doses, friendly to the produce, but resulting in (a) the inability of treated mites to reproduce and/or (b) the inhibition of mite development should be used [1]. The effects of ionizing radiation on tetranychid mites belonging to the following species have been studied so far: *Tetranychus urticae* Koch [2-7], *T. arabicus* Attiah [8-10], *Panonychus citri* (McGregor) [11], *P. ulmi* Koch [12] and *Oligonychus biharensis* (Hirst.) [13]. Effects of ionizing radiation on the two-spotted spider mite have been investigated in details, but there is no information in the literature on the susceptibility to ionizing radiation of the carmine spider mite, *T. cinnabarinus* (Boid.), a closely related species.

The carmine spider mite is a cosmopolitan species with a range of hosts, including weeds, ornamental plants, fruit trees, vegetable crops, and greenhouse plants. Infested host plants are yellowish or brownish, and heavily covered with webs which affect their photosynthesis. Feeding of mites results in crumpling, curling, and twisting leaves, which eventually dry-up and fall-off. Growth, flowering and fruit setting of horticultural plants is always severely affected. Economic importance of these mites is especially significant in subtropical and tropical countries. The two-spotted spider mite is a typical polyphagous and cosmopolitan pest. It infests more than 300 plant species belonging to different families. Feeding symptoms and damage to the host plants of the two-spotted spider mite are similar to those caused by the carmine spider mite. In the present study, the effects of gamma radiation on development of immature stages, fecundity, and fertility of adults of the two-spotted spider mite and the carmine spider mite were investigated and compared to determine the doses required for a quarantine treatment.

## 2. MATERIAL AND METHODS

Spider mites were obtained from a greenhouse at the Warsaw Agricultural University, where they were reared on the common bean (*Phaseolus vulgaris* L.) at 20-25$^{o}$C, 70$\pm$5%R.H., and under a long day photoperiod (16:8 L:D). For experiments, mites were kept on detached leaf cultures. A culture consisted of glass dish (6 cm diam.) containing cotton wool saturated in water. A young bean leaf was pressed on top of a wad of cotton wool and this leaf rooted usually after some days. Such leaf cultures remained fresh for about 3-4 weeks under the rearing and experimental conditions. A number of leaf cultures were placed in a tray containing a little water. This water formed an isolating barrier between the various cultures and prevented desiccation of the leaves [14].

Young mites were obtained by separating them from the stock colony in the last quiescent stage before adulthood (teleiochrysalis), and they were placed on the leaf culture. Several young males and females of the spider mites were placed on the leaves, and females were allowed to produce eggs. Every other day, the mites were transferred to new leaf cultures, producing 'waves' of eggs left in the previously used leaf cultures. About 10 such transfers were made. The eggs were then incubated at 22$\pm$2$^{o}$C, 70-80% R.H., under a long day photoperiod. After the last transfer, mites at different ages and stages of development were obtained and then irradiated with gamma radiation.

Mites (eggs, immature stages of known age, and adult males and females) on detached leaf cultures were irradiated with a Co-60 source installed at the Faculty of Veterinary, Warsaw Agricultural University. The dose rate was 48.3 Gy/min. A Fricke dosimeter was used for calibration [15]. The irradiator was operated at ca. 20$^{o}$C and 50-60% R.H. Mites were treated with the following doses of gamma radiation: 0 (control), 50, 100, 200, 300, and 400 Gy. Spider mites belonging to both species were simultaneously treated with the same dose. After irradiation, mites were held under the rearing conditions described above. After irradiation, mites were reared until adult emergence. Development, number, and percent developing to the next stage of irradiated eggs, larvae, and nymphs were recorded. Adults (F1) were sexed and the sex ratio of their progeny was calculated. Every 3 to 4 days, treated adult mites were transferred to fresh leaf cultures. The mortality of females was recorded for 3 weeks, and the number of eggs produced was noted. Emerged larvae were reared to obtain the F1 adults. Males and females of the F1 generation were paired to obtain adults of the F2 generation. Fecundity and fertility of irradiated females of the P generation, and the sex ratio of the F 1 and F2 progeny were recorded.

## 3. RESULTS

### 3.1. Effects of gamma radiation on development of immature stages of the carmine spider mite and the two-spotted spider mite

#### *3.1.1. Irradiation of eggs*

The data obtained indicate a positive relationship between dosage and percent egg mortality (Tables I and II). Mortality of 4-5-day-old eggs of the carmine spider mite was 36, 60, 81, and 95% after treatment with doses of 100, 200, 300, and 400 Gy, respectively. The respective mortalities of the oldest eggs of the two-spotted spider mite treated with the same dosages were 52, 66, 89, and 99%. Complete or almost 100% mortality of spider mite eggs was obtained when 0-2-day-old eggs received a dose of 100 Gy or higher. The oldest eggs were the most resistant to radiation, and only irradiation of them with a dose of 400 Gy resulted in almost complete mortality (94.8%).

TABLE I. DEVELOPMENT OF GAMMA-IRRADIATED EGGS OF THE CARMINE SPIDER MITE, *T. cinnabarinus*

| Dose (Gy) | Age of eggs (days) | Number of eggs | Eggs to larvae (%) | Eggs to protonymphs (%) | Eggs to deutonymphs (%) | Eggs to adults (%) |
|---|---|---|---|---|---|---|
| 100 | 0-1 | 173 | 1.7 | 0.6 | 0 | 0 |
| | 1-2 | 175 | 2.9 | 1.7 | 0 | 0 |
| | 2-3 | 164 | 18.9 | 12.2 | 11.0 | 10.4 |
| | 3-4 | 195 | 35.4 | 27.1 | 25.1 | 22.1 |
| | 4-5 | 132 | 63.6 | 52.3 | 40.2 | 37.9 |
| 200 | 0-1 | 166 | 0 | 0 | 0 | 0 |
| | 1-2 | 139 | 0 | 0 | 0 | 0 |
| | 2-3 | 163 | 0.6 | 0 | 0 | 0 |
| | 3-4 | 154 | 9.0 | 2.6 | 1.3 | 0.7 |
| | 4-5 | 204 | 40.2 | 12.3 | 6.9 | 5.4 |
| 300 | 0-1 | 199 | 0 | 0 | 0 | 0 |
| | 1-2 | 166 | 0 | 0 | 0 | 0 |
| | 2-3 | 211 | 0 | 0 | 0 | 0 |
| | 3-4 | 189 | 6.9 | 2.6 | 0.5 | 0 |
| | 4-5 | 214 | 19.2 | 3.7 | 0.9 | 0.5 |
| 400 | 0-1 | 135 | 0 | 0 | 0 | 0 |
| | 1-2 | 135 | 0 | 0 | 0 | 0 |
| | 2-3 | 141 | 0 | 0 | 0 | 0 |
| | 3-4 | 165 | 0 | 0 | 0 | 0 |
| | 4-5 | 172 | 5.2 | 2.9 | 0.6 | 0.6 |
| Control | 0-5 | 730 | 84.9 | 84.0 | 81.9 | 81.1 |

TABLE II. DEVELOPMENT OF GAMMA-IRRADIATED EGGS OF THE TWO-SPOTTED SPIDER MITE, *T.urticae*

| Dose (Gy) | Age of eggs (days) | Number of eggs | Eggs to larvae (%) | Eggs to protonymphs (%) | Eggs to deutonymphs (%) | Eggs to adults (%) |
|---|---|---|---|---|---|---|
| 100 | 0-1 | 141 | 2.8 | 0.7 | 0.7 | 0 |
| | 1-2 | 170 | 2.9 | 1.8 | 0.6 | 0.6 |
| | 2-3 | 160 | 8.1 | 8.1 | 7.5 | 7.5 |
| | 3-4 | 127 | 68.5 | 61.4 | 58.3 | 55.9 |
| | 4-5 | 184 | 47.8 | 45.1 | 42.3 | 40.2 |
| 200 | 0-1 | 200 | 0 | 0 | 0 | 0 |
| | 1-2 | 144 | 0 | 0 | 0 | 0 |
| | 2-3 | 158 | 1.3 | 0.6 | 0 | 0 |
| | 3-4 | 107 | 10.3 | 2.8 | 0 | 0 |
| | 4-5 | 116 | 33.6 | 28.4 | 22.4 | 19.8 |
| 300 | 0-1 | 149 | 0.7 | 0 | 0 | 0 |
| | 1-2 | 221 | 0 | 0 | 0 | 0 |
| | 2-3 | 213 | 3.8 | 2.8 | 1.4 | 1.4 |
| | 3-4 | 133 | 0.8 | 0 | 0 | 0 |
| | 4-5 | 130 | 11.5 | 8.5 | 3.4 | 3.1 |
| 400 | 0-1 | 148 | 0 | 0 | 0 | 0 |
| | 1-2 | 148 | 0 | 0 | 0 | 0 |
| | 2-3 | 123 | 0 | 0 | 0 | 0 |
| | 3-4 | 133 | 3.0 | 0 | 0 | 0 |
| | 4-5 | 151 | 0.7 | 0 | 0 | 0 |
| Control | 0-5 | 767 | 82.4 | 81.6 | 80.4 | 79.9 |

Eggs of both species exposed to gamma radiation early in embryonic development were considerably more susceptible to irradiation than older eggs. Exposure of 0-1-day-old eggs of *T. cinnabarinus* to 100 Gy caused 98.3% mortality, whereas only 36.4% of the 4-5-day-old eggs died after the treatment with the same dose. The tolerance of eggs to gamma radiation increased in 3-4-day-old eggs, when eye-spots were formed.

At low doses, a significant number of eggs hatched, but deleterious effects of irradiation were reflected by mortality in subsequent stages. Tables I and II summarize the effects of egg irradiation on survival of subsequent developmental stages. A gradual increase of mortality of immature stages developing from irradiated eggs was usually observed in both spider mite species.

No adults of the carmine spider mite developed from (a) 0-2-day-old eggs exposed to a dose of 100 Gy or higher, (b) 2-3-day-old eggs exposed to a dose of 200 Gy or higher, and (c) 3-4-day-old eggs exposed to a dose of 300 or 400 Gy. When the oldest eggs were exposed to 100, 200, 300, and 400 Gy, adult survivors were 37.9, 5.4, 0.5, and 0.6%, respectively. More than 80% of eggs developed to adult stage in the control (Table I). Similar results were recorded for the two-spotted spider mite (Table II). A small percent of adults emerging from irradiated old eggs of both spider mite species exhibited malformations of the hind pair of legs, or their whole body was malformed. The sex ratio of adults developing from irradiated old eggs was affected by the treatment. The sex ratio of the carmine spider mite was 2.46 (no. of females : no. of males) in the control, but it was reduced to 1.97 in adults developing from eggs treated with a dose of 100 Gy (Table III). A more pronounced effect was observed in the two-spotted spider mite, in which the sex ratio was 3.79 in the control, and only 1.8 in adults from irradiated eggs (Table IV).

TABLE III. SEX RATIO OF CARMINE SPIDER MITES, *T. cinnabarinus*, THAT DEVELOPED FROM IRRADIATED IMMATURE STAGES

| Dose (Gy) | Developmental stage treated | Sex ratio | | |
|---|---|---|---|---|
| | | Number of females | Number of males | Females:males |
| | eggs* | 73 | 37 | 1.97 |
| 100 | larvae | 46 | 26 | 1.77 |
| | nymphs | 60 | 43 | 1.40 |
| | eggs* | 8 | 4 | - |
| 200 | larvae | 16 | 23 | 0.70 |
| | nymphs | 41 | 42 | 0.98 |
| | eggs* | 0 | 1 | - |
| 300 | larvae | 9 | 9 | - |
| | nymphs | 33 | 31 | 1.06 |
| | eggs* | 0 | 1 | - |
| 400 | larvae | 0 | 0 | - |
| | nymphs | 1 | 3 | - |
| Control | - | 421 | 171 | 2.46 |

* 4-5-day-old eggs were irradiated.

TABLE IV. SEX RATIO OF TWO-SPOTTED SPIDER MITES, *T. urticae*, THAT DEVELOPED FROM IRRADIATED IMMATURE STAGES

| Dose (Gy) | Developmental stage treated | Sex ratio | | |
|---|---|---|---|---|
| | | Number of females | Number of males | Females:males |
| | eggs* | 99 | 59 | 1.8 |
| 100 | larvae | 38 | 14 | 2.71 |
| | nymphs | 49 | 50 | 0.98 |
| | eggs* | 20 | 3 | - |
| 200 | larvae | 21 | 24 | 0.88 |
| | nymphs | 60 | 37 | 1.62 |
| | eggs* | 5 | 2 | - |
| 300 | larvae | 8 | 17 | - |
| | nymphs | 61 | 62 | 0.98 |
| | eggs* | 0 | 0 | - |
| 400 | larvae | 1 | 3 | - |
| | nymphs | 0 | 1 | - |
| Control | - | 485 | 128 | 3.79 |

* 4-5-day-old eggs were irradiated.

*3.1.2. Irradiation of larvae*

At low doses (100 or 200 Gy), a significant number of larvae developed to the protonymph or deutonymph stage, and more than 60% of them reached the adult stage. Deleterious effects of irradiation of larvae with a higher doses were reflected in mortality of subsequent stages. Tables V and VI summarize the effects of irradiation of larvae on survival of subsequent developmental stages. A gradual increase of mortality of immature stages that developed from irradiated larvae was usually observed in both spider mite species.

TABLE V. DEVELOPMENT OF GAMMA-IRRADIATED LARVAE OF THE CARMINE SPIDER MITE, *T. cinnabarinus*

| Dose (Gy) | Number of larvae | Larvae to protonymphs (%) | Larvae to deutonymphs (%) | Larvae to adults (%) |
|---|---|---|---|---|
| 100 | 72 | 86.1 | 75.0 | 63.9 |
| Control | 61 | 95.1 | 90.2 | 86.9 |
| 200 | 63 | 87.3 | 79.4 | 61.9 |
| Control | 85 | 96.5 | 95.3 | 95.3 |
| 300 | 81 | 66.7 | 50.6 | 22.2 |
| Control | 113 | 95.6 | 88.5 | 88.5 |
| 400 | 104 | 5.8 | 3.8 | 0.0 |
| Control | 78 | 96.2 | 96.2 | 94.9 |

TABLE VI. DEVELOPMENT OF GAMMA-IRRADIATED LARVAE OF THE TWO-SPOTTED SPIDER MITE, *T. urticae*

| Dose (Gy) | Number of larvae | Larvae to protonymphs (%) | Larvae to deutonymphs (%) | Larvae to adults (%) |
|---|---|---|---|---|
| 100 | 82 | 84.1 | 69.6 | 63.4 |
| Control | 103 | 99.0 | 99.0 | 96.1 |
| 200 | 73 | 89.0 | 76.7 | 61.6 |
| Control | 52 | 100.0 | 96.2 | 90.4 |
| 300 | 81 | 72.8 | 59.3 | 30.9 |
| Control | 49 | 98.0 | 98.0 | 98.0 |
| 400 | 99 | 26.3 | 14.1 | 4.0 |
| Control | 87 | 97.7 | 90.8 | 90.8 |

No adults of the carmine spider mite developed from larvae exposed to 400 Gy, and only 4% adults of the two-spotted spider mites developed from larvae treated with the same dose of gamma radiation. These data indicate that larvae of the spider mites are less susceptible to irradiation than eggs. The sex ratio of adults was affected by radiation treatment of larvae. The sex ratio of the carmine spider mite was 2.46 (no. of females : no. of males) in the control, whereas it was lowered to 1.77 and 0.7 in adults that developed from larvae treated with doses of 100 and 200 Gy, respectively (Table III). A more pronounced effect was observed in the two-spotted spider mite, in which the sex ratio was 3.79 in the control, and 2.71 and 0.88 in adults that originated from larvae irradiated with 100 and 200 Gy, respectively (Table IV).

*3.1.3. Irradiation of nymphs*

Tables VII and VIII summarize the effects of irradiation of protonymphs on survival of subsequent developmental stages. Mortality of spider mites that developed from irradiated protonymphs increased with increase of absorbed dose of gamma radiation. A few adults of the carmine spider mite and the two-spotted spider mite developed from protonymphs irradiated with a dose of 400 Gy. Protonymphs of the spider mites are more resistant to gamma radiation than eggs and larvae.

TABLE VII. DEVELOPMENT OF GAMMA-IRRADIATED PROTONYMPHS OF THE CARMINE SPIDER MITE, *T. cinnabarinus*

| Dose (Gy) | Number of protonymphs treated | Protonymphs to deutonymphs (%) | Protonymphs to adults (%) |
|---|---|---|---|
| 100 | 125 | 86.4 | 82.4 |
| Control | 136 | 91.2 | 86.0 |
| 200 | 119 | 85.7 | 69.7 |
| Control | 150 | 86.0 | 84.0 |
| 300 | 148 | 75.7 | 43.2 |
| Control | 161 | 96.9 | 95.0 |
| 400 | 121 | 7.4 | 3.3 |
| Control | 157 | 92.9 | 90.4 |

TABLE VIII. DEVELOPMENT OF GAMMA-IRRADIATED PROTONYMPHS OF THE TWO-SPOTTED SPIDER MITE, *T. urticae*

| Dose (Gy) | Number of protonymphs treated | Protonymphs to deutonymphs (%) | Protonymphs to adults (%) |
|---|---|---|---|
| 100 | 126 | 88.9 | 78.6 |
| Control | 158 | 93.7 | 81.6 |
| 200 | 154 | 82.5 | 43.0 |
| Control | 154 | 90.3 | 85.1 |
| 300 | 199 | 81.9 | 61.8 |
| Control | 150 | 89.3 | 84.0 |
| 400 | 147 | 17.0 | 0.7 |
| Control | 203 | 89.2 | 86.2 |

The sex ratio of adults that developed from irradiated nymphs was affected by the treatment. The sex ratio of the carmine spider mite was 2.46 in the control, whereas it was 1.4, 0.98, and 1.06 in adults that developed from nymphs treated with a dose of 100, 200, and 300 Gy, respectively (Table III). More pronounced effect was observed in the two-spotted spider mite: the sex ratio was 3.79 in the control, and 0.98, 1.62, 0.98 in adults that originated from nymphs irradiated with 100, 200 and 300 Gy, respectively (Table IV).

### 3.2. Effects of gamma radiation on fecundity and fertility of the carmine spider mite and the two-spotted spider mite

Two-day-old females of the carmine spider mite and the two-spotted spider mite irradiated with 200 or 300 Gy lived as long as the controls. Mortality occurred after 3 weeks (Tables IX and X). Data on mortality of gamma irradiated females of the carmine spider mite and the two-spotted spider mite irradiated as 7-10 day-old adults are summarized in Tables XI and XII. Control females of the carmine spider and females irradiated with 50 Gy dose lived longer than 21 days, whereas females irradiated with 100, 200, and 300 Gy were all dead after 21, 21, and 15 days, respectively (Table XI). Similar results were recorded for the two-spotted spider mite (Table XII).

Irradiated females of the carmine spider mite produced eggs only during the first two weeks after treatment, but the controls laid eggs during the total observation period. The number of eggs laid by irradiated females was considerably lower than in the control. A dose of 300 Gy reduced fecundity by about 61% (Table XIII). Females of the two-spotted spider mite treated with 300 Gy produced eggs only during the first two weeks after the treatment, but those irradiated with 200 Gy and the controls laid eggs during the total observation period. Number of eggs laid by irradiated females was considerably lower than in the control, and it decreased as the absorbed dose increased. A dose of 300 Gy did not inhibit completely production of eggs by treated females, but it reduced fecundity by about 70% (Table XIV). The effect of irradiation on spider mite fecundity was more pronounced, when 7-10 day old females were treated. However, the highest dose tested did not inhibit the production of eggs by aged females (Tables XV and XVI).

TABLE IX. MORTALITY (%) OF GAMMA-IRRADIATED FEMALES OF THE CARMINE SPIDER MITE, *T. cinnabarinus*, IRRADIATED AS 2-DAY- OLD FEMALES

| Dose (Gy) | 200 | 300 | Control |
|---|---|---|---|
| Number of females | 35 | 17 | 29 |
| Days after irradiation | | | |
| 0-3 | 8.6 | 23.5 | 0.0 |
| 3-7 | 11.4 | 47.0 | 13.8 |
| 7-10 | 34.3 | 52.9 | 27.6 |
| 10-14 | 48.6 | 52.9 | 37.9 |
| 14-17 | 57.1 | 76.5 | 58.6 |
| 17-21 | 62.8 | 82.3 | 86.2 |
| >21 | 100.0 | 100.0 | 100.0 |

TABLE X. MORTALITY (%) OF GAMMA-IRRADIATED FEMALES OF THE TWO-SPOTTED SPIDER MITE, *T. urticae*, IRRADIATED AS 2-DAY- OLD FEMALES

| Dose (Gy) | 200 | 300 | Control |
|---|---|---|---|
| Number of females | 26 | 28 | 14 |
| Days after irradiation | | | |
| 0-3 | 11.5 | 10.7 | 0.0 |
| 3-7 | 19.2 | 21.4 | 0.0 |
| 7-10 | 26.9 | 32.1 | 0.0 |
| 10-14 | 26.9 | 46.4 | 21.4 |
| 14-17 | 42.3 | 46.4 | 50.0 |
| 17-21 | 50.0 | 50.0 | 57.1 |
| >21 | 100.0 | 100.0 | 100.0 |

TABLE XI. MORTALITY (%) OF GAMMA-IRRADIATED FEMALES OF THE CARMINE SPIDER MITE, *T. cinnabarinus*, IRRADIATED AS 7-10- DAY-OLD ADULTS

| Dose (Gy) | 50 | 100 | 200 | 300 | Control |
|---|---|---|---|---|---|
| Total number of females | 69 | 58 | 61 | 73 | 76 |
| Days after irradiation | | | | | |
| 0-3 | 7.2 | 19.0 | 13.1 | 30.1 | 3.9 |
| 3-6 | 18.8 | 72.4 | 62.3 | 80.8 | 6.6 |
| 6-9 | 27.5 | 74.1 | 62.3 | 90.4 | 14.5 |
| 9-12 | 31.9 | 75.9 | 65.6 | 98.6 | 18.4 |
| 12-15 | 40.6 | 93.1 | 67.2 | 100.0 | 22.4 |
| 15-18 | 50.7 | 98.3 | 88.5 | | 36.8 |
| 18-21 | 65.2 | 100.0 | 100.0 | | 51.3 |
| >21 | 100.0 | | | | 100.0 |

TABLE XII. MORTALITY (%) OF GAMMA-IRRADIATED FEMALES OF THE TWO SPOTTED SPIDER MITE, *T. urticae*, IRRADIATED AS 7-10- DAY-OLD ADULTS

| Dose (Gy) | 50 | 100 | 200 | 300 | Control |
|---|---|---|---|---|---|
| Total number of females | 65 | 58 | 63 | 71 | 72 |
| Days after irradiation | | | | | |
| 0-3 | 7.7 | 12.1 | 30.2 | 81.7 | 4.2 |
| 3-6 | 41.5 | 13.8 | 34.9 | 88.7 | 4.2 |
| 6-9 | 52.3 | 13.8 | 49.2 | 91.5 | 5.6 |
| 9-12 | 69.2 | 17.2 | 58.2 | 97.2 | 9.7 |
| 12-15 | 72.3 | 37.9 | 65.1 | 98.6 | 16.7 |
| 15-18 | 75.3 | 56.9 | 77.8 | 100.0 | 18.1 |
| 18-21 | 93.8 | 98.3 | 100.0 | | 30.6 |
| >21 | 100.0 | 100.0 | | | 100.0 |

TABLE XIII. FECUNDITY AND FERTILITY OF FEMALES OF THE CARMINE SPIDER MITE, *T. cinnabarinus*, IRRADIATED AS 2-3- DAY- OLD FEMALES

| Dose (Gy) | Number of females observed | Number of eggs laid (number of eggs per female*) | Viability of eggs (%) |
|---|---|---|---|
| 200 | 17 | 125 (7.4) | 58.4 |
| 300 | 35 | 537 (15.3) | 11.7 |
| Control | 29 | 1374 (47.4) | 93.4 |

*Number of eggs per female laid during a week period.

TABLE XIV. FECUNDITY AND FERTILITY OF FEMALES OF THE TWO-SPOTTED SPIDER MITE, *T. urticae*, IRRADIATED AS 2-3-DAY-OLD FEMALES

| Dose (Gy) | Number of females observed | Number of eggs laid (number of eggs per female*) | Viability of eggs (%) |
|---|---|---|---|
| 200 | 29 | 515 (17.8) | 49.5 |
| 300 | 28 | 374 (13.4) | 3.2 |
| Control | 14 | 1250 (89.3) | 94.0 |

*Number of eggs per female laid during a week period.

TABLE XV. FECUNDITY AND FERTILITY OF FEMALES OF THE CARMINE SPIDER MITE, *T. cinnabarinus*, IRRADIATED AS 7-10-DAY-OLD FEMALES

| Dose (Gy) | Number of females observed | Number of eggs laid (number of eggs per female*) | Viability of eggs (%) |
|---|---|---|---|
| 50 | 69 | 919 (13.3) | 77.3 |
| 100 | 58 | 257 (4.4) | 61.5 |
| 200 | 61 | 206 (3.4) | 49.7 |
| 300 | 73 | 120 (1.6) | 4.8 |
| Control | 76 | 1788 (23.5) | 77.4 |

*Number of eggs per female laid during a 3 day period

TABLE XVI. FECUNDITY AND FERTILITY OF FEMALES OF THE TWO-SPOTTED SPIDER MITE, *T. urticae*, IRRADIATED AS 7-10-DAY-OLD FEMALES

| Dose (Gy) | Number of females observed | Number of eggs laid (number of eggs per female*) | Viability of eggs (%) |
|---|---|---|---|
| 50 | 65 | 614 (9.4) | 74.5 |
| 100 | 58 | 223 (3.8) | 68.4 |
| 200 | 63 | 248 (3.9) | 41.7 |
| 300 | 71 | 52 (0.7) | 11.1 |
| Control | 72 | 1161 (16.1) | 81.3 |

*Number of eggs per female laid during a 3 day period.

Viability of eggs laid by irradiated females of spider mites kept with irradiated males was significantly reduced. Young (2-3-day-old) females treated with a dose of 200 Gy produced 40-50% nonviable eggs, while the control mites produced only 6.0-6.6% nonviable eggs. A dose of 300 Gy caused high mortality of eggs; 88% and 97% nonviable eggs were found for the carmine spider mite and the two-spotted spider mite, respectively. In general, viability of eggs produced by mites irradiated as young females (Tables XIII and XIV) and old females (Tables XV and XVI) was similar. The higher the dose of gamma radiation applied to adults of the spider mites, the higher the mortality of offspring during their embryonic development. However, a dose of 300 Gy did not cause sterility. To determine a sterilizing dose for both sexes, spider mites were irradiated with 300, 320, 340, 360, 380, and 400 Gy. Hatchability of eggs produced by treated mites is presented in Table XVII. Data obtained indicate that a dose of 320 Gy is the lowest dose causing sterility in the carmine spider mite and the two-spotted spider mite, when both males and females were irradiated.

Mites emerged from eggs laid by irradiated females were reared on the bean leaves to the adult stage. Their mortality during the development was recorded (Tables XVIII-XX). Mortality of control mites during the embryonic and post-embryonic development was similar and it ranged from 4.3 to 6.6%, whereas in the treatments most mites died during embryonic development. Mortality of treated mites during the post-embryonic development was low (<6%) and similar to the control. Only in immatures that developed from eggs laid by *T. cinnabarinus* females irradiated with a 200 Gy dose did post-embryonic mortality reach the level of 14.4% (Table XVIII). However, when the percent of mortality of immatures during the post-embryonic development is referred to the total number of emerged larvae, then it may be stated that the highest mortality during the post-embryonic development occurred in progeny originated from eggs laid by 300 Gy-treated females than in mites originated from 200 Gy-treated females and in the control (Table XX).

TABLE XVII. DETERMINATION OF A DOSE OF GAMMA RADIATION CAUSING STERILITY OF BOTH SEXES OF THE CARMINE SPIDER MITE AND THE TWO-SPOTTED SPIDER MITE

| Spider mite species | Dose (Gy) | Number of eggs observed | Viability of eggs (%) |
|---|---|---|---|
| *T. cinnabarinus* | Control | 1374 | 93.4 |
| | 300 | 537 | 11.7 |
| | 310 | 421 | 6.5 |
| | 320 | 370 | 0.0 |
| | 330 | 367 | 0.0 |
| | 340 | 314 | 0.0 |
| | 350 | 298 | 0.0 |
| | 360 | 280 | 0.0 |
| | 380 | 293 | 0.0 |
| | 400 | 178 | 0.0 |
| *T. urticae* | Control | 1250 | 94.0 |
| | 300 | 374 | 3.2 |
| | 310 | 453 | 2.5 |
| | 320 | 389 | 0.0 |
| | 330 | 290 | 0.0 |
| | 340 | 267 | 0.0 |
| | 350 | 250 | 0.0 |
| | 360 | 185 | 0.0 |
| | 380 | 243 | 0.0 |
| | 400 | 107 | 0.0 |

TABLE XVIII. MORTALITY OF PROGENY OF IRRADIATED FEMALES (2-3-DAY-OLD) OF SPIDER MITES DURING THE EMBRYONIC AND POST-EMBRYONIC DEVELOPMENT

| Mite species | Dose (Gy) | Number of eggs observed | Mortality (%) | | |
|---|---|---|---|---|---|
| | | | Embryonic development | Post-embryonic development | Total |
| | 200 | 125 | 41.6 | 14.4 | 56.0 |
| *T. cinnabarinus* | 300 | 537 | 88.3 | 5.8 | 94.1 |
| | control | 1374 | 6.6 | 5.6 | 12.2 |
| | 200 | 515 | 50.5 | 4.3 | 54.8 |
| *T. urticae* | 300 | 374 | 96.8 | 2.7 | 99.5 |
| | control | 1250 | 6.0 | 4.3 | 10.3 |

The F1 generation was obtained in treatments involving irradiation of adults with 200 and 300 Gy. The sex ratio of the F1 progeny developed from irradiated females was affected by the irradiation, and it was very low. There were more males than females in the treatments than in the control. The sex ratio of the carmine spider mite was 2.3 (number of females : number of males) in the control, whereas it was reduced to about 0.6 in the F1 adults that developed from females treated with a dose of 200 and 300 Gy. Similar effects were found for the two-spotted spider mite. The sex ratio was 2.3 and 0.3 in the control and in progeny from females that were irradiated with 200 Gy, respectively (Table XXI). In the next generation (F2) the value of sex ratio increased and was similar or only slightly lower than in the control (Table XXII).

TABLE XIX. DEVELOPMENT OF EGGS LAID BY GAMMA-IRRADIATED FEMALES OF SPIDER MITES

| Mite species | Dose (Gy) | Number of eggs observed | Eggs to larvae (%) | Eggs to protonymphs (%) | Eggs to deutonymphs (%) | Eggs to adult stage (%) |
|---|---|---|---|---|---|---|
| | 300 | 537 | 11.7 | 10.6 | 7.2 | 5.9 |
| *T. cinnabarinus* | 200 | 125 | 58.4 | 55.2 | 49.6 | 44.0 |
| | control | 1374 | 93.4 | 92.2 | 89.4 | 87.8 |
| | 300 | 374 | 3.2 | 1.6 | 0.8 | 0.5 |
| *T. urticae* | 200 | 515 | 49.5 | 48.1 | 46.6 | 45.2 |
| | control | 1250 | 94.0 | 92.3 | 90.6 | 89.7 |

TABLE XX. MORTALITY OF IMMATURES ORIGINATED FROM IRRADIATED FEMALES OF SPIDER MITES DURING THE POST-EMBRYONIC DEVELOPMENT

| Mite species | Dose (Gy) | Number of larvae | Mortality of immatures at the indicated developmental stages: number (%) dead mites | | | |
|---|---|---|---|---|---|---|
| | | | Larva | Protonymph | Deutonymph | Total |
| | 300 | 63 | 6 (9.5) | 18 (28.6) | 7 (11.1) | 31 (49.2) |
| *T.cinnabarinus* | 200 | 73 | 4 (5.5) | 7 (9.6) | 7 (9.6) | 18 (24.7) |
| | control | 1283 | 16 (1.2) | 39 (3.0) | 22 (1.7) | 77 (6.0) |
| | 300 | 12 | 6 (50.0) | 3 (25.0) | 1 (8.3) | 10 (83.3) |
| *T. urticae* | 200 | 255 | 7 (2.7) | 8 (3.1) | 7 (2.7) | 22 (8.6) |
| | control | 1175 | 21 (1.8) | 21 (1.8) | 12 (1.0) | 54 (4.6) |

TABLE XXI. SEX RATIO OF THE F1 PROGENY DEVELOPED FROM EGGS LAID BY IRRADIATED FEMALES OF SPIDER MITES

| Mite species | Dose (Gy) | Number of eggs observed | Number (%) of F1 adults developed | Sex ratio | | |
|---|---|---|---|---|---|---|
| | | | | Number of females | Number of males | Females: males |
| | 300 | 537 | 32 (6.0) | 12 | 20 | 0.6 |
| *T. cinnabarinus* | 200 | 125 | 55 (44.0) | 22 | 33 | 0.6 |
| | 0 | 1374 | 1206 (87.8) | 843 | 363 | 2.32 |
| | 300 | 374 | 3 (0.8) | 0 | 3 | - |
| *T. urticae* | 200 | 515 | 233 (45.2) | 57 | 176 | 0.32 |
| | 0 | 1250 | 1121 (89.7) | 780 | 341 | 2.29 |

TABLE XXII. SEX RATIO OF THE F2 PROGENY DEVELOPED FROM EGGS LAID BY THE F1 FEMALES ORIGINATED FROM IRRADIATED FEMALES OF SPIDER MITES

| Mite species | Dose (Gy) | Number of eggs observed | Number (%) of F1 adults developed | Sex ratio | | |
|---|---|---|---|---|---|---|
| | | | | Number of females | Number of males | Females: males |
| | 300 | 928 | 791 (85.2) | 511 | 280 | 1.82 |
| *T. cinnabarinus* | 200 | 2225 | 1677 (75.4) | 1133 | 544 | 2.08 |
| | 0 | 1374 | 1206 (87.8) | 843 | 363 | 2.32 |
| *T. urticae* | 200 | 1991 | 1284 (64.5) | 818 | 466 | 1.75 |
| | 0 | 1250 | 1121 (89.7) | 780 | 341 | 2.29 |

## 4. DISCUSSION

Several papers on the effects of ionizing radiation on the spider mites *(Tetranychidae)* have been published, and general information on these effects has been amassed. According to these data, the deteriorative effects of radiation on spider mites include lethality, reduced longevity, delayed molting, ceasing of oviposition, reduced fecundity (ovipositional rate), egg sterility, reduction of egg hatch, delayed embryonic and postembryonic development, and disturbance in the sex ratio of progeny. These effects occur at certain dose levels. Application of ionizing radiation to mite control problems appears promising in two ways: radiation can be applied in doses lethal to the population, or in doses which sterilize the pests.

Lethal effects of high doses of ionizing radiation on adults of the spider mites have not been studied. However, from studies on other mite pests it appears that the mites are very resistant to irradiation, and doses higher than 2 kGy are required for immediate mortality of the acarid mites *(Acaridae)* [1]. High doses of ionizing radiation resulting in accelerated mortality of mites are not recommended as they may cause phytotoxicity to horticultural produce. Lower doses, friendly to the produce, but resulting in (a) the inability of treated mites to reproduce, and/or (b) the inhibition of the development should be suggested [15].

### 4.1. Effects of gamma radiation on development of immature stages of the carmine spider mite and the two-spotted spider mite

The effects of ionizing radiation on developmental stages of the spider mites previously have been studied only in the two-spotted spider mite and *T. arabicus* [2, 8, 9, 16]. In general, these results are in agreement with those obtained in the present study. Tolerance of spider mite eggs to ionizing radiation (gamma rays, electron beam) increases with increased age. Eggs irradiated at an early stage of embryonic development are considerably more susceptible than those exposed at later stages. A large shift in susceptibility of eggs occurs in 3-day-old eggs. Irradiation of eggs results usually in retardation of embryonic and postembryonic development. It results in high mortality of larvae and nymphs that hatched from treated eggs. Fecundity and fertility of adults that emerged from irradiated eggs is also much affected. Goodwin and Wellham [5] observed that survivors of eggs treated with 150 Gy and 300 Gy completed their development at a slower rate. At 150 Gy, females laid 0.09 eggs per female per day. At 300 Gy, females failed to develop to maturity, and no eggs were laid. We found that a few adult mites (up to 3%) developed from old (4-5-day-old) eggs treated with a dose of 300 Gy, but none at a dose of 400 Gy (Tables I and II).

Some authors [2, 8] have reported that haploid (unfertilized ) eggs are more susceptible to irradiation than diploid (fertilized) eggs fated to be female. However, data from this study (Tables III and IV) do not support these findings, but indicate the effect of irradiation on the sex ratio in mites that developed from irradiated eggs is strongly biased towards males.

Larvae of spider mites were not killed immediately by treatment with a dose ≤400 Gy, and some of them completed their development. No adults of the carmine spider mite developed from larvae exposed to a 400 Gy dose, and only 4% adults developed from larvae treated with this dose of gamma radiation (Tables V and VI). Goodwin and Wellham [5] reported that no larvae treated at 600 Gy or higher completed their development. Also Wakid *et al.* [16] noted that larvae of *T. arabicus* suffered high mortality at 500 Gy, and at 600 Gy adult emergence from treated larvae was completely inhibited. These data indicate that larvae of spider mites are less susceptible to irradiation than eggs.

Wakid et al. [16] found that *T. arabicus* males emerging from irradiated larvae were more susceptible to the treatment than females. At 200 Gy, a few males were able to mature, while at 250 Gy all emerged adults were females. We observed that the sex ratio of adults that originated from treated larvae was shifted towards males in both mite species (Tables III and IV).

Irradiation of larvae results in reduced number of adults developing from them, and in delayed and incomplete development. Females that emerged from irradiated larvae produce fewer eggs than the controls, fewer progeny, and more non-viable eggs. At 300 Gy, females of *T. arabicus* were sterile [16]. Irradiation of spider mite nymphs results in reduction of adult emergence and/or delayed adult emergence. Mites at this stage are more resistant to irradiation than eggs and larvae. Elbadry et al. [9] noted that treated deutonymphs were able to develop to the adult stage at 2,100 Gy. However, sublethal doses of gamma radiation (80-300 Gy) applied to nymphs significantly reduced longevity, fecundity, and fertility of adults. We found that a few adults emerged from protonymphs treated with 400 Gy, but at lower doses a significant number of nymphs completed their development. The sex ratio was biased towards males.

### 4.2. Effects of gamma radiation on fecundity and fertility of the carmine spider mite and the two-spotted spider mite.

The effects of low doses of ionizing radiation on longevity of spider mite adults were considered only by Goodwin and Wellham [5], Dohino and Tanabe[2], and Bhuiya *et al.* [13]. Goodwin and Wellham [5] observed no mortality over periods of 0-4 days and 5-12 days after gamma irradiation in two-spotted spider mite females irradiated with doses as high as 1,200 Gy. However, Dohino and Tanabe [2] found that the survival rate of irradiated *T. urticae* females slowly decreased 5 days after irradiation with electron beams applied in doses up to 800 Gy, while that of non-irradiated females rapidly decreased on the 7th day after irradiation and was lower than that of irradiated females on the 9-10th day after irradiation. The inequality of survival rate in irradiated females was found to reverse on the 12th day after irradiation. A clear relationship between dose and survival rate of the two-spotted spider mite was not found by these authors. Bhuiya *et al.* [13] observed gradual decrease of longevity in *O. biharensis* adults treated with gamma radiation. Control males died after 20 days but males irradiated with 100, 200, 300, 400, and 500 Gy died after 13, 15, 13, 9, and 8 days, respectively. In the present study, we found that the survival rates of control females of the carmine spider mite and the two-spotted spider mite and females irradiated with 200 or 300 Gy of gamma radiation were similar. Complete mortality of both control and treated mites occurred after 3 weeks (Tables IX and X). Aged females (7-10 day old) of the carmine spider mite irradiated with 100, 200, and 300 Gy were all dead after 21, 21, and 15 days, respectively; whereas control females irradiated with 50 Gy lived longer than 21 days (Table XI). Similar results were recorded for the two-spotted spider mite (Table XII).

Dohino and Tanabe [2] reported that ovipositional rate (eggs/female/day) of irradiated females rapidly declined in the first 7 days and oviposition stopped on the 17th, 10th, 7th, and 7th day after irradiation with 200, 400, 600, and 800 Gy of electron beams, respectively. Similar results are reported in the present study with the carmine spider mite and the two-spotted spider mite. Irradiated females of the carmine spider mite produced eggs only during the first two weeks after the treatment, but controls laid eggs during the total observation period. As a consequence, the fecundity (number of eggs laid per female) of irradiated females was greatly affected (Tables XIII-XVI). Somewhat different results were reported by Goodwin and Wellham [5]. They noted that ovipositional rate was similar during both the 0-4 day and 5-12 day periods after the treatment in young (1 day old) and old (5 day old) *T. urticae* females treated with the same dose of gamma radiation. However, they found that ovipositional rate decreased as the dose of irradiation increased.

Viability of eggs produced by adults of the spider mites irradiated with low doses is usually significantly reduced. We noted that irradiation with 300 Gy caused high mortality of eggs; 88% and 97% nonviable eggs were found in the carmine spider mite and the two-spotted spider mite, respectively. The higher the dose of gamma radiation applied to adults of the spider mites, the higher the mortality of mites during their embryonic development (Tables XIII-XVI). Complete sterility of both sexes was produced by a dose of 320 Gy (Table XVII). Table XXIII summarizes data of different authors on the doses of ionizing radiation causing the sterility in females, males or both sexes of the spider mites. Doses needed for *T. urticae* female sterility range from 200 Gy to 400 Gy, and for male sterility from 300 to 350 Gy. When both sexes were irradiated, doses in the range of 300 to 400 Gy caused sterility. Doses of 300, 280, and 300 Gy sterilized females, males, and both sexes of *T. arabicus*, respectively [10].

Dohino and Tanabe [2] observed at 200 kGy dose that hatchability of *T. urticae* eggs recovered from 0.6-2.1% in the first 7 days up to 28.5-46.2% in the next 7 days. Also, Goodwin and Wellham [5] noted that at 150 Gy more eggs laid in the first 4 days were sterile (99%) than eggs laid 5-12 days after irradiation (87-91%). Recovery of egg viability was also observed in acarid mites. Almost all the eggs laid during the first 2 weeks after treatment of *T. putrescentiae* adults with 90 Gy were dead. Later, viability of eggs produced by these mites gradually increased to 74% [1]. Eggs of mites before and after oviposition differ in their susceptibility to irradiation. Szlendak *et al.* [19] found that spermatogonia and spermatozoa are more tolerant than spermatocytes and spermatids to electron beams. They suggested that primary gonial cells repopulate testes after irradiation at 300 Gy and less. It may be that egg cells and oogonia of mites are more tolerant to ionizing radiation than oocytes. Electron beam irradiation is similar to gamma irradiation in sterility effect for spider mites [2] and for acarid mites [20].

TABLE XXIII. DOSES OF IONIZING RADIATION CAUSING STERILITY IN FEMALES, MALES, OR BOTH SEXES OF SPIDER MITES

| Spider mite species | Sterilizing dose (Gy) for | | | Reference |
|---|---|---|---|---|
| | Females | Males | Both sexes | |
| *Oligonychus biharensis* | - | - | 200 | [13] |
| *Panonychus citri* | 320 | 240 | - | [11] |
| *Tetranychus arabicus* | 300 | 280 | 300 | [9, 10] |
| *T. cinnabarinus* | - | - | 320 | this paper |
| *T. urticae* | 400 | - | - | [2] |
| *T. urticae (= T. telarius* L.) | 320 | 320 | - | [6] |
| *T. urticae* | - | - | 300 | [5] |
| *T. urticae* | 200 | 300 | - | [7] |
| *T. urticae* | - | - | 320 | this paper |
| *T. urticae* | - | 350 | - | [17] |
| *T. urticae* | 400 | - | - | [18] |
| *T. urticae* | 80 | 240 | - | [4] |

Henneberry [6] reported that untreated females of the two-spotted spider mite mated with males exposed to a dose in the 80-240 Gy range produced fewer females and more nonviable eggs than females of untreated pairs. Untreated females mated to males exposed to 320 Gy produced only males and nonviable eggs. Females exposed to 80 Gy and mated to untreated males produced fewer female progeny than untreated pairs. Females irradiated with 160 Gy produced fewer females and males that the untreated controls. However, the sex ratio (no. of females : no. of males) was 2.5, as was the ratio in the control. Females exposed to 240 Gy and 320 Gy and mated to untreated males produced a few progeny or only nonviable eggs.

At doses 1,120 Gy and 1,280 Gy, more males and fewer nonviable eggs were produced. Henneberry [6] interpreted the effect produced by these doses as sperm injury or sperm activation. Fertilization of eggs did not occur to produce diploid females and the mated females responded as if unmated. In *T. arabicus* and *P. citri*, at doses >800 Gy, untreated females mated to treated males produced more males and fewer nonviable eggs, indicating the induction of sperm injury [9-11]. Sperm inactivation was also observed in the acarid mite, *Tyrophagus putrescentiae* (Schrank), by Ignatowicz *et al.* [21] after irradiation of adult mites with a dose of or higher.

The sex ratio of the citrus red mite was close to 1:1 in the control, and it was variably affected by irradiation. Treated females mated to untreated males produced less viable eggs and variable percent of females as the dose increased. At a dose 160 Gy, mites produced 43.4% viable eggs, and about 14 % females were found among progeny that developed from these eggs. The corresponding data for 240 Gy were 21% viable eggs and 41.2% females. At 320 Gy, treated females were sterile and they produced only nonviable eggs [11].

When both sex of *T. arabicus* were treated with gamma radiation, the sex ratio in their progeny decreased as the dose increased. The control sex ratio was 1.77, and it decreased to 0.65 at a dose of 80 Gy. A few progeny was obtained from mite pairs irradiated with 160 Gy, and their sex ratio was 0.29 (2 females and 7 males). When treated females were mated to untreated males, the sex ratio in progeny of the parent generation increased with the dose, and at 240 kGy mite pairs produced only females [10].

Somewhat different results are reported from our studies with irradiated females and males of the two-spotted spider mite and the carmine spider mite. We found that the sex ratio in the control spider mites was about 2.3, and it was significantly biased in progeny of irradiated parents. Usually, F1 males developed from eggs produced by treated females, and males were more numerous than females in both spider mite species studied (Table XXI). In the F2 generation, the sex ratio increased and approached the control value, indicating post radiation recovery (Table XXII).

The effects of irradiation on the sex ratio in progeny of treated mites is evident. We found that the sex ratio is usually skewed towards sons after the treatment. Factors such as irradiation which influence sex-ratio are critical to mite population growth rates. Because daughters determine growth, the proportion of offspring that are female affects the rate of population increase. Furthermore, as adult females are the dispersing stage [22], sex ratio is important to population expansion.

Data on premature mortality of mites that emerged from eggs produced by irradiated adults of *T. arabicus* were provided only by Wakid *et al.* [9, 10]. They noted that mortality of mites during post-embryonic development (larvae, nymphs) was very low, not exceeding 8.0%. In the present study, we found that mortality of progeny from irradiated adults of spider mites during the post-embryonic development was also low, similar to the control, and in the most cases not exceeding 6.0%. One exception was that progeny of 200 Gy-treated adults of the carmine spider mite was 14.4%) (Table XVIII). The highest mortality of mites during post-embryonic development occurred at the protonymphal stage (Table XX).

## 5. CONCLUSIONS

Mortality of 4-5-day-old eggs of the carmine spider mite was 81 and 95% after treatment with 300 or 400 Gy, respectively. The respective mortalities of the oldest eggs of the two-spotted spider mite treated with the same dosages were 89 and 99%. Complete or almost 100% mortality of spider mite eggs was obtained when 0-2-day-old eggs received a dose of 100 Gy or higher. The oldest eggs were the most resistant to radiation, and only irradiation of them with a dose of 400 Gy resulted in almost complete mortality (94.8%). No adults of the carmine spider mite developed from 3-4-day-old eggs exposed to 300 or 400 Gy. When the oldest eggs of the two-spotted spider mite were exposed to 300 Gy and 400 Gy, adult survivors were 0.5% and 0.6%, respectively. A small percent of adults that emerged from irradiated old eggs of both spider mite species exhibited malformations of the hind pair of legs, or their whole body was malformed. The sex ratio of adults that developed from irradiated old eggs was affected by the treatment.

Deteriorative effects of irradiation of larvae with a higher doses were reflected by mortality in subsequent stages. A gradual increase of mortality of immature stages developed from irradiated larvae was usually observed in both spider mite species. No adults of the carmine spider mite developed from larvae exposed to a 400 Gy dose, and only 4% adults of the two-spotted spider mites originated from larvae treated with the same dose of gamma radiation. Sex ratio of adults developed from irradiated larvae was affected by the treatment.

Gamma irradiation of protonymphs affected the survival of their subsequent developmental stages. Mortality of subsequent stages of spider mites originated from irradiated protonymphs increased with the increase of the absorbed dose of gamma radiation. A few adults of the carmine spider mite and the two-spotted spider mite developed from protonymphs irradiated with a 400 Gy dose. Protonymphs of the spider mites were more resistant to gamma radiation than eggs and larvae. Sex ratio of adults developed from irradiated nymphs was affected by the treatment. Sex ratio of the carmine spider mite was 2.46 in the control, whereas it was lowered to 1.06 in adults developed from nymphs treated with a dose of 300 Gy. More pronounced effect was observed in the two-spotted spider mite: the sex ratio was 3.79 in the control, and 0.98 in adults originated from nymphs irradiated with 300 Gy.

Two-day-old females of the carmine spider mite and the two-spotted spider mite irradiated with 300 Gy lived as long as the controls. Their complete mortality occurred after 3 weeks. Control females of the carmine spider mite lived longer than 21 days, whereas females irradiated with 300 Gy were all dead after 15 days. The similar results were recorded for the two-spotted spider mite. Irradiated females of the carmine spider mite produced eggs only during the first two weeks after the treatment, but the controls laid eggs during the total observation period. Number of eggs laid by irradiated females was considerably lower than in the control. A dose of 300 Gy reduced the fecundity by about 61%. Females of the two-spotted spider mite treated with 300 Gy produced eggs only during the first two weeks after the treatment. Number of eggs laid by irradiated females was considerably lower than in the control, and it decreased as the absorbed dose increased. Viability of eggs laid by irradiated females of spider mites kept with irradiated males was significantly reduced. A dose of 300 Gy caused the high mortality of eggs; 88% and 97% nonviable eggs were found for the carmine spider mite and the two-spotted spider mite, respectively. Viability of eggs produced by mites irradiated as young females and old females was similar. The higher the dose of gamma radiation applied to adults of the spider mites, the higher the mortality of offspring during their embryonic development. A dose of 320 Gy was found to be the lowest dose causing sterility in the carmine spider mite and the two-spotted spider mite, when both males and females were irradiated.

Higher mortality during the post-embryonic development occurred in progeny originated from eggs laid by females treated with 300 Gy than in mites that originated from females treated with 200 Gy and in the control. The F1 generation was obtained in treatments involving irradiation of adults with 200 and 300 Gy. The sex ratio of the F1 progeny that developed from irradiated females was affected by the irradiation, and there were more males than females in the treatments. In the next generation (F2) the value of sex ratio increased and was similar or only slightly lower than in the control.

According to the above data, gamma irradiation as a quarantine treatment for spider mites *(Tetranychus urticae, T. cinnabarinus)* in cut flowers, vegetables, some fruits, and other agricultural commodities may be applied at doses higher than 320 Gy, which is friendly to the produce, but results in the inability of treated mites to reproduce and/or the inhibition of their development.


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