MORPHOLOGICAL CHANGES OF PEPPER VARIETIES (*CAPSICUM ANNUUM* L.) RESULTED FROM UV-C LIGHTS AND GAMMA-RAY RADIATION SOURCES

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Abstract. Mutation breeding is a method frequently used in plant breeding programs to develop high-yielding varieties that are resistant to biotic and abiotic environmental factors and to determine genetic diversity. This study aimed to determine the effects of different doses of ultraviolet light and gamma rays on the morphological characteristics of some pepper varieties (Çermik (local variety), Kandil and Üçburun). The experiment was realized in Dicle University, Faculty of Agriculture, Department of Horticulture laboratory and polycarbonate greenhouse. In the paper, the effects of different gamma ray doses (0, 50, 100, 200, 300, 400 and 500 Gy) and ultraviolet light sources kept on 0.5 and 1.0-m distances under priming and non-priming conditions for one and 2 h were assessed on root and shoot development, leaf color and proline values of pepper seedlings. A notable reduction realized in root collar diameter, root length, plant fresh weight, root fresh weight, root dry weight, plant dry weight, color values (l, a, b) and proline content of pepper varieties with increasing doses of gamma ray radiation. The ultraviolet light sources kept on 0.5 and 1.0 m significantly resulted in changes in all features. Consequently, ultraviolet light sources were more effective for genetic diversity than gamma rays. Finally, 200-300 Gy dosses and ultraviolet light kept on 0.5 m were more efficient than other treatments. In the future, it will be effective to investigate the effects of these treatments and their combinations to obtain mutants with desired characters.

Keywords: *plant breeding, physical mutation, mutagenic agent, genetic diversity, pepper seedling*

Introduction

Pepper (Capsicum sp.) is a significant source of vegetable supply on a global scale, cultivated extensively in tropical and subtropical regions. Pepper is producted by 38.310.427 tons from 2.065.408 hectares area in the world (FAO, 2023). Pepper yield in the world was 18.55 tons average, and the Netherlands (269.2 tons/ha), Belgium (256.2 tons/ha) and Germany (115.4 tons/ha) ranked the highest yield in 2023, respectively. Türkiye has many species due to genetic diversity and ranked sixth by yield of 40.4 tons/ha (FAO, 2023). Capia pepper is the most produced species by 1.602.457 tons production, followed by pointed pepper (939.178 tons), bell pepper (395.441 tons) and paprika (143.934 tons) (TURKSTAT, 2023).

Currently, Turkey performs well in terms of production, although it has yet to attain the desired level. The high performance of the seed to be used in production for quality, yield, ecological adaptation and durability increases the preferability of varieties (Akalp and Pirinc, 2024b). Therefore, there is a need to increase genetic diversity and develop new varieties that are highly productive and resistant to biotic and abiotic environmental factors in plant breeding program. For this purpose, gene mutations can be artificially triggered by some physical and chemical mutagenic agents and new varieties can be produced by increasing the genetic diversity of peppers (Jo and Kim, 2019; Neeraj and Kumar, 2022). Using different physical

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(gamma rays, X-rays, UV rays) and chemical (diethyl sulfate, sodium azide, and ethyl metal sulfonate) mutagens has provided to obtain a large number of genetic diversity with the desired character in a shorter time and at a lower cost (Krupa-Małkiewicz et al., 2017; Gerami et al., 2017). Hybrid seeds, which are obtained as a result of hybridization of parents with superior and desired characteristics, are made more efficient by showing different characteristics from their ancestors (Hayward et all. 1993). These seeds have been developed using many breeding methods in the past and are still being developed. Although the breeding process started with classical breeding, tissue culture methods, anther culture, biotechnological methods, it continued with many different methods with the integration of new methods and technologies, mutation breeding is one of these methods (Kökpınar et al., 2021; Maurya and Bahadur, 2022; Akalp and Pirinç, 2024b). Indeed, mutation breeding is more advantageous in terms of time and labor in determining individuals with target traits and genetic diversity compared to traditional breeding. Mutagenic agents are effective in improving targeted traits and accurately explaining gene activity by increasing phenotypic and genotypic diversity. Many studies have been conducted on mutagenic activity in different pepper species. Aslam et al. (2017) argued that different caffeine doses reduced germination percentage, crop survival, root length and shoot length of peppers. Arumingtyas and Ahyar (2022) noted that gamma-ray radiation could induce diversity in morphological features of peppers. Akalp and Pirinç (2024a) reported that increasing gamma rays and EMS mutagens reduced plant height of peppers and increased the variations. Similarly, Dongfu et al. (2022) identified some mutations by EMS doses in the leaf shape, flower organ, stem, leaf color, fertility and fruit shape of the pepper. Moreover, Castilejo et al. (2022) stated that ultraviole light (UV-C) affected on physicochemical quality of peppers. UV-B radiation contributes to genetic variation by changing biochemical composition (Rajashekara et al., 2021), morphology, phenolic compound production, gene expression, and related drought stress responses (Rodríguez-Calzada et al., 2019).

In the paper, the effects of different doses of gamma rays (0, 50, 100, 200, 300, 400, and 500 Gy) and ultraviolet light source under priming and non-priming conditions for one and 2 h on pepper varieties were examined to increase genetic diversity for morphological features.

Materials and methods

Plant and mutation material

Three pepper varieties including Çermik, Kandil and Üçburun were used in experiment. Çermik genotypes is a local genotype and chosen among the lines of selection breeding, Kandil and Üçburun are commercial varieties adapted to region conditions. The physical mutations included ^{60}Co gamma rays (power 2.07 kGy/h) and ultraviolet light sources.

Mutation processing

The source of gamma rays was ^{60}Co (power 2.07 kGy/h) irradiated at the Turkish Atomic Energy Authority (TENMAK). Ultraviolet light (irradiation) was treated (Philips TUV, Netherlands; model T8; 30 W / 1 kJ m^{-2}) in Dicle University, Department of Horticulture laboratory.

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Plant growing and experimental design

The all seeds treated with both mutations were sown at the same day in greenhouse conditions. The seeds of treated and the control group were sown together in 2:1 mortar mixture in 45 plots of viols. The substrates used in mortar material was torf–perlite in a ratio of 2:1. The mutant plants were grown in Dicle University, Department of Horticulture's polycarbonate greenhouse of 25°C the day and 22°C at night. The experiment was conducted in greenhouse conditions based on split plots in randomized plots with 5 replications for each treatment and each replications included 45 plants. The experiment was finished 45 days after sowing. Plants were washed in tap water, and following such as root collar diameter, root length, plant fresh weight, root fresh weight, root dry weight, plant dry weight, color values (l, a, b) and proline of mutant plants were measured.

Data analysis

The obtained data were analyzed in the JMP-7 statistical package program based on the date were analyzed in JMP-7 statistical program based on randomized plots experimental design. The differences between the means were compared by the LSD (Least Significant Difference) test at 0.05 level.

Results and discussion

The results of analysis of the investigated features were given in *Tables 1* and *2*. The gamma rays and ultraviolet light (UV-C) treatments significantly affected the examined features of the pepper varieties.

Effects of gamma irradiation

The increased doses of gamma rays were significantly affected on parameters in all three pepper seedlings ($P \leq 0.01$). The highest root collar diameter obtained from control group in Kandil (1.37 mm) and Çermik (1.32 mm) varieties. Üçburun variety given the highest value in control (1.71 mm) and 50 Gy (1.70 mm), respectively. The increased doses reduced the root collar diameter in all varieties. *Table 1*). These findings are similar to findings reported by Yıldız (2020) stated many morphological variations in green beans occurred by increasing gamma doses.

Root length reduced in all varieties by increasing gamma dose-dependent. The highest value was detected in control group in Kandil (8.92 cm), Üçburun (6.83 cm) and Çermik (5.55 cm) varieties, respectively. The lowest root length was in 600 Gy in Çermik variety (1.33 cm). In the 50, 100, 200 and 300 Gy doses increased in root length of Üçburun and Çermik varieties. In Üçburun pepper seedlings, the highest root length was found in control to 200 Gy treatments, while the shortest root length was found in 500 and 600 Gy radiation doses (3.99-3.10 cm). In seedlings of Çermik genotype, the highest root length was in the control group in 100 Gy dose (5.55-5.40 cm), while the shortest root length was in 500 and 600 Gy doses (2.09-1.33 cm) (*Table 1*). Similarly, some researchers also stated that root length reduced by increasing gamma doses (Tepe et al., 2003; Sood et al., 2016; Kantoğlu, 2022).

The highest plant fresh weight was obtained from the seedlings of Kandil variety in the control group (0.33 g), and the lowest value was obtained from the 400-500-600 Gy doses (0.06, 0.05 and 0.04 g, respectively). Control group, 50, 100 and 200 Gy doses

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given higher value than other treatments in Üçburun variety. In Çermik genotype, the seedlings in the control group had the highest plant fresh weight (0.53 g), while the seedlings exposed to 400, 500 and 600 doses had the lowest value (0.08, 0.06 and 0.04 g, respectively) (*Table 1*). Similarly, Yıldız (2020) reported that plant weight decreased in parallel with the presence of increasing doses.

Root fresh weight was the highest in control group of Kandil (0.32 G), Üçburun (0.21 g) and Çermik (0.15 g) varieties, respectively. 50 Gy doses increased in Üçburun by 0.20 g. In Çermik variety, 50, 100 and 200 Gy doses significantly affected root fresh weight by values ranging from 0.09 to 0.14 g. Additionally, the highest root and plant dry weight were obtained from the control group for three varieties (*Table 1*).

In plants, l* value indicates brightness and l* = 0 corresponds to black and l* = 100 corresponds to white, +b value indicates yellowness, -b value indicates blueness, +a value indicates redness, and -a value indicates greenness. For the l value, control group given high value in Çermik variety (44.57) followed by control group of Kandil (41.99) and Üçburun (39.78), respectively. 50 and 100 Gy doses given in high value in Kandil and Çermik varieties, while 50, 100, 200, 300, 400 and 500 Gy doses given similar and high value in Üçburun variety (*Table 1*).

For the a* value was more intense in the control group in Üçburun variety (-26.18), and it was observed that red tones dominated by 400, 500 and 600 Gy (-21.22, -21.58, -19.01, respectively). The highest value was in Üçburun (-15.65) and Kandil (-19.01) in 600 Gy dose, while Çermik variety given the highest value in control group (-17.94). The b* value was highest in 100 Gy dose (43.20%) in Çermik variety, and yellow tones were dominant in the plant. In addition, Kandil and Üçburun variety given the highest value in control group by 40.25 and 37.46, respectively. As the increased and reached 500-600, the b* value was found to be the lowest (25.76-22.90) and blue tones dominated in the plants (*Table 1*). Similarly, some researchers also argued that mutagenic agents changed in the physio-biochemical features, leaf color in peppers (Cheng et al., 2019; Shamsiah et al., 2022).

The proline content increased in 500 and 600 Gy doses in all varieties. 600 Gy dose given the highest proline content in Üçburun (0.67 μmol g^{-1}), followed by Çermik (0.65 μmol g^{-1}) and Kandil (0.63 μmol g^{-1}) (*Table 1*). Similarly, Louali et al. (2015) reported that the amount of proline decreased with increasing gamma doses.

Effects of UV-C radiation

The UV-C kept on 0.5 m and 1.0 m levels was significantly affected on seedling growth (*Table 2*). The plant height of Kandil variety was higher in wet + 1 h + 1.0 m treatments (12.53 cm), followed by priming (wet) (12.53 cm) and non-priming (dry) control (12.31 cm) conditions than other treatments. In Üçburun variety, the highest plant height was determined in dry + 1 h + 0.5 m (19.20 cm) treatment, followed by dry + 2 h + 1.0 m (19.10 cm), non-priming control (18.88 cm), priming + 1 h + 1.0 m (18.48 cm), priming control (18.10 cm) and dry + 1 h + 1.0 m (16.75 cm) treatments. Çermik variety given the highest plant height in priming control (11.94 cm) and non-priming + 2 h + 0.5 m treatments (11.64 cm) (*Table 2*). Additionally, Zlatev (2012) reported that plants exposed to UV radiation were stressed and the plant height decreased. Lee et al. (2014) stated that plant growth reduced because of exposing to UV-C.

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Table 1. *The effects of gamma ray treatments on examined morphological features of pepper seedlings*

	Treatments	Root collar diameter (mm)	Root length (cm)	Plant fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Plant dry weight (g)	l* Color content	a* Color content	b* Color content	Proline (µmol g^{-1})
Kandil	Control group	1.37 ± 0.03 a	8.92 ± 0.27 a	0.33 ± 0.01 a	0.32 ± 0.01 a	0.02 ± 0.00 a	0.07 ± 0.01 a	41.99 ± 1.57 a	-25.34 ± 0.26 cd	40.25 ± 0.47 a	0.55 ± 0.01 b
	50	1.01 ± 0.03 b	7.30 ± 0.29 b	0.25 ± 0.01 b	0.16 ± 0.01 b	0.02 ± 0.00 a	0.07 ± 0.00 a	40.18 ± 1.33 ab	-25.68 ± 0.44 d	38.44 ± 0.30 a	0.55 ± 0.01 b
	100	0.60 ± 0.01 c	4.41 ± 0.09 c	0.10 ± 0.00 c	0.03 ± 0.00 c	0.01 ± 0.00 c	0.02 ± 0.00 b	35.00 ± 3.36 abc	-21.19 ± 1.77 ab	29.65 ± 1.30 b	0.54 ± 0.01 b
	200	0.49 ± 0.01 d	3.29 ± 0.09 d	0.08 ± 0.00 cd	0.02 ± 0.00 c	0.01 ± 0.00 b	0.02 ± 0.00 b	32.00 ± 0.49 cd	-24.20 ± 0.49 bcd	30.32 ± 0.37 b	0.54 ± 0.01 b
	300	0.42 ± 0.01 de	3.22 ± 0.09 d	0.07 ± 0.00 cd	0.02 ± 0.00 c	0.01 ± 0.00 b	0.02 ± 0.00 b	32.75 ± 1.15 bc	-22.26 ± 0.51 abcd	28.78 ± 0.50 bc	0.57 ± 0.01 b
	400	0.36 ± 0.01 ef	3.16 ± 0.09 d	0.06 ± 0.00 de	0.02 ± 0.00 c	0.01 ± 0.00 bc	0.01 ± 0.00 b	30.46 ± 1.47 cd	-21.22 ± 0.52 ab	27.56 ± 0.24 bc	0.57 ± 0.01 b
	500	0.30 ± 0.01 fg	3.10 ± 0.09 d	0.05 ± 0.00 de	0.01 ± 0.00 c	0.01 ± 0.00 bc	0.01 ± 0.00 b	27.85 ± 0.60 cd	-21.58 ± 0.67 abc	25.76 ± 0.67 cd	0.65 ± 0.01 a
	600	0.24 ± 0.02 g	3.01 ± 0.09 d	0.04 ± 0.01 e	0.01 ± 0.01 c	0.01 ± 0.00 bc	0.01 ± 0.00 b	24.76 ± 0.52 d	-19.01 ± 0.52 a	22.90 ± 0.60 d	0.63 ± 0.02 a
	LSD $_{(0.05)}$	0.69**	4.12**	0.19**	0.20**	0.01**	0.05**	9.69**	4.10**	8.83**	0.08**
Üçburun	Control group	1.71 ± 0.04 a	6.83 ± 0.12 a	0.46 ± 0.03 a	0.21 ± 0.00 a	0.09 ± 0.01 a	0.05 ± 0.00 a	39.78 ± 2.01 a	-26.18 ± 2.41 c	37.46 ± 2.66 a	0.53 ± 0.01 b
	50	1.70 ± 0.03 a	6.81 ± 0.12 a	0.45 ± 0.03 a	0.20 ± 0.00 a	0.02 ± 0.00 b	0.01 ± 0.00 bc	38.87 ± 1.97 ab	-19.08 ± 0.89 ab	27.21 ± 2.05 b	0.55 ± 0.01 b
	100	1.63 ± 0.03 ab	6.78 ± 0.12 a	0.41 ± 0.03 a	0.17 ± 0.00 b	0.01 ± 0.00 b	0.00 ± 0.00 c	38.79 ± 0.37 ab	-20.80 ± 0.57 b	24.22 ± 0.99 b	0.54 ± 0.01 b
	200	1.55 ± 0.03 ab	6.72 ± 0.12 a	0.42 ± 0.02 a	0.12 ± 0.00 c	0.01 ± 0.00 b	0.01 ± 0.00 b	38.92 ± 0.36 ab	-18.35 ± 0.53 ab	25.10 ± 0.77 b	0.55 ± 0.01 b
	300	1.50 ± 0.03 b	6.68 ± 0.12 b	0.24 ± 0.02 b	0.08 ± 0.00 d	0.01 ± 0.00 b	0.01 ± 0.00 b	36.64 ± 0.88 ab	-18.34 ± 0.44 ab	23.71 ± 0.47 b	0.57 ± 0.01 b
	400	0.63 ± 0.05 c	4.06 ± 0.20 b	0.10 ± 0.02 c	0.03 ± 0.01 e	0.01 ± 0.00 b	0.01 ± 0.00 b	34.26 ± 0.43 ab	-17.42 ± 0.50 ab	24.48 ± 0.52 b	0.57 ± 0.01 b
	500	0.59 ± 0.05 c	3.99 ± 0.20 c	0.09 ± 0.02 c	0.03 ± 0.01 e	0.01 ± 0.00 b	0.01 ± 0.00 b	36.24 ± 0.78 ab	-16.89 ± 0.50 ab	24.53 ± 0.52 b	0.64 ± 0.01 a
	600	0.55 ± 0.06 c	3.10 ± 0.20 c	0.07 ± 0.02 c	0.02 ± 0.01 e	0.01 ± 0.00 b	0.01 ± 0.00 b	33.62 ± 1.22 b	-15.65 ± 0.48 a	24.16 ± 0.58 b	0.67 ± 0.02 a
	LSD $_{(0.05)}$	0.98**	2.99**	0.34**	0.14**	0.06**	0.03**	5.47**	6.03**	8.34**	0.06**
Çermik	Control group	1.32 ± 0.02 a	5.55 ± 0.19 a	0.53 ± 0.02 a	0.15 ± 0.02 a	0.10 ± 0.01 a	0.07 ± 0.00 a	39.03 ± 0.92 abc	-17.94 ± 0.52 a	26.56 ± 1.23 d	0.56 ± 0.01 c
	50	1.27 ± 0.02 ab	5.48 ± 0.19 a	0.48 ± 0.02 ab	0.14 ± 0.02 a	0.02 ± 0.00 b	0.01 ± 0.00 b	43.31 ± 4.37 ab	-19.57 ± 1.17 ab	39.60 ± 2.52 ab	0.56 ± 0.01 c
	100	1.21 ± 0.02 ab	5.40 ± 0.19 a	0.42 ± 0.02 bc	0.13 ± 0.02 a	0.01 ± 0.00 b	0.01 ± 0.00 b	36.17 ± 1.98 abc	-24.77 ± 1.01 c	43.20 ± 3.12 a	0.58 ± 0.01 bc
	200	1.17 ± 0.02 ab	4.32 ± 0.19 b	0.34 ± 0.02 c	0.09 ± 0.01 ab	0.02 ± 0.00 b	0.01 ± 0.00 b	44.57 ± 2.99 a	-21.27 ± 0.41 abc	32.73 ± 1.81 bcd	0.61 ± 0.01 abc
	300	1.16 ± 0.06 b	3.41 ± 0.23 bc	0.15 ± 0.02 d	0.03 ± 0.01 bc	0.01 ± 0.00 b	0.01 ± 0.00 b	35.21 ± 0.91 abc	-21.47 ± 0.65 bc	36.40 ± 1.43 abc	0.58 ± 0.01 bc
	400	0.47 ± 0.03 c	2.52 ± 0.25 cd	0.08 ± 0.02 de	0.01 ± 0.01 c	0.02 ± 0.00 b	0.01 ± 0.00 b	34.22 ± 0.40 bc	-24.04 ± 0.48 c	34.31 ± 0.77 bcd	0.63 ± 0.02 ab
	500	0.51 ± 0.03 c	2.09 ± 0.31 de	0.06 ± 0.02 de	0.01 ± 0.01 c	0.01 ± 0.00 b	0.01 ± 0.00 b	34.44 ± 0.56 abc	-23.82 ± 0.45 c	31.00 ± 1.06 bcd	0.64 ± 0.02 ab
	600	0.46 ± 0.03 c	1.33 ± 0.25 e	0.04 ± 0.02 e	0.01 ± 0.01 c	0.01 ± 0.00 b	0.01 ± 0.00 b	32.79 ± 0.82 c	-22.81 ± 0.71 bc	30.13 ± 0.76 cd	0.65 ± 0.01 a
	LSD $_{(0.05)}$	0.66**	2.98**	0.35**	0.13**	0.05**	0.03**	9.93**	4.37**	10.23**	0.07**

**Significant at 0.01 levels, respectively. Levels not connected by same letter are significantly different

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Table 2. *The effects of UV-C radiation treatments on examined morphological features of pepper seedlings*

	Treatment	Plant height (cm)	Root length (cm)	Root diameter (mm)	Plant fresh weight (g)	Root fresh weight (g)	Plant dry weight (g)	Root dry weight (g)	L* Color content	a* Color content	b* Color content	Proline (µmol g^{-1})
	Dry+1h+0.5m	9.77±0.31 bc	4.19±0.22 cde	1.12±0.04 bc	0.35±0.02 bc	0.14±0.01 abc	0.03±0.00 bcd	0.01±0.00 b	32.26±1.47 c	-15.01±0.91 a	18.88±0.86 b	0.77±0.01 bcd
	Dry+1h+1.0m	11.52±0.21 ab	5.89±0.12 abc	1.55±0.07 ab	0.34±0.02 bcd	0.18±0.01 ab	0.18±0.00 a	0.02±0.01 a	43.23±0.82 ab	-20.98±0.57 c	24.80±1.25 a	0.77±0.02 bcd
	Wet+1h+0.5m	11.32±0.37 ab	4.41±0.33bcde	1.24±0.08 abc	0.46±0.02 ab	0.11±0.01 bc	0.03±0.00 cd	0.01±0.00 b	31.41±2.40 c	-15.63±1.09 ab	21.02±0.71 ab	0.82±0.01 bc
	Wet+1h+1.0m	12.38±0.55 a	7.17±0.39 a	1.65±0.07 a	0.35±0.02 bcd	0.16±0.03 ab	0.03±0.00 bcd	0.01±0.00 b	41.48±0.79 ab	-19.07±0.46 bc	20.50±0.69 ab	0.65±0.01 de
Kandil	Dry+2 h+0.5m	11.58±0.47 ab	3.97±0.21 de	1.06±0.13 c	0.49±0.05 a	0.15±0.02 abc	0.03±0.00 bc	0.01±0.00 b	31.72±2.01 c	-15.92±0.77 ab	20.47±0.68 ab	0.97±0.05 a
	Dry+2h+1.0m	10.93±0.47 ab	5.65±0.26abcd	1.55±0.07 ab	0.35±0.03 bcd	0.14±0.01 abc	0.02±0.00 d	0.01±0.00 b	43.18±1.24 ab	-18.56±0.72 abc	21.79±1.05 ab	0.84±0.01 b
	Wet+2h+0.5m	8.35±0.22 cd	3.65±0.37 e	1.24±0.07 abc	0.28±0.01 cd	0.08±0.01 c	0.04±0.00 b	0.01±0.00 b	31.96±1.17 c	-16.38±0.75 ab	19.80±1.02 ab	1.01±0.05 a
	Wet+2h+1.0m	7.60±0.37 d	4.72±0.24bcde	1.31±0.12 abc	0.23±0.02 d	0.18±0.02 ab	0.02±0.00 cd	0.01±0.00 b	45.95±1.00 a	-20.73±0.50 c	23.64±1.18 ab	0.70±0.01 cde
	Dry control	12.31±0.47 a	5.57±0.52abcd	1.48±0.09 abc	0.36±0.01 bc	0.20±0.02 a	0.02±0.00 cd	0.01±0.00 b	37.34±1.19 bc	-17.31±0.72 abc	23.28±1.58 ab	0.62±0.01 e
	Wet control	12.53±0.48 a	5.93±0.58 ab	1.23±0.18 abc	0.39±0.03 abc	0.12±0.02 bc	0.03±0.00 bcd	0.02±0.00 ab	33.67±1.30 c	-16.27±0.75 ab	22.15±0.80 ab	0.61±0.01 e
	LSD $_{(0.05)}$	7.41**	6.72**	0.53**	0.19**	0.18**	0.06**	0.01**	7.89**	8.06**	4.28**	7.12**
	Dry+1h+0.5m	10.31±0.29 b	4.42±0.49 e	0.86±0.03 c	0.25±0.03 cde	0.05±0.01 bc	0.02±0.00	0.01±0.00 bc	33.43±3.08 b	-16.82±1.55 b	20.47±1.44 ab	0.81±0.01 cd
	Dry+1h+1.0m	16.75±0.76 a	8.05±0.57 b	1.50±0.04 ab	0.27±0.02 cde	0.12±0.01 abc	0.03±0.00	0.01±0.00 abc	41.91±0.69 a	-18.34±0.64 b	19.84±1.27 ab	0.72±0.01 d
	Wet+1h+0.5m	8.10±0.40 b	9.57±3.94 a	1.00±0.05 c	0.24±0.02 de	0.04±0.01 c	0.02±0.00	0.00±0.00 c	32.84±2.35 b	-6.81±4.93 a	20.23±1.22 ab	0.89±0.01 c
	Wet+1h+1.0m	18.48±0.28 a	6.84±0.47 d	1.58±0.02 a	0.34±0.02 cd	0.12±0.01 abc	0.02±0.00	0.02±0.01 ab	41.42±0.71 a	-18.94±0.43 b	20.55±0.89 ab	0.72±0.01 d
	Dry+2 h+0.5m	9.82±0.39 b	5.01±0.59 e	1.02±0.03 c	0.24±0.03 cde	0.06±0.01 bc	0.06±0.03	0.01±0.00 bc	33.36±1.05 b	-15.94±0.59 b	20.71±0.83 ab	1.12±0.02 a
Üçburun	Dry+2h+1.0m	19.20±0.74 a	7.72±0.70 c	1.65±0.06 a	0.47±0.04 ab	0.15±0.02 abc	0.04±0.00	0.01±0.00 abc	40.84±0.64 a	-18.80±0.65 b	20.16±0.54 ab	1.00±0.04 b
	Wet+2h+0.5m	8.65±0.31 b	4.16±0.62 e	0.92±0.04 c	0.21±0.02 e	0.04±0.01 c	0.01±0.00	0.00±0.00 c	32.71±1.06 b	-15.28±0.89 ab	18.85±1.00 b	1.09±0.03 ab
	Wet+2h+1.0m	19.10±0.35 a	7.02±0.40 c	1.69±0.01 a	0.35±0.01 bcd	0.10±0.01 abc	0.05±0.01	0.02±0.00 a	40.36±0.48 a	-18.36±0.83 b	19.00±1.02 b	0.88±0.02 c
	Dry control	18.88±0.67 a	7.63±0.63 c	1.35±0.04 b	0.36±0.02 bc	0.24±0.09 a	0.02±0.00	0.00±0.00 c	43.73±0.82 a	-20.63±0.63 b	24.59±1.29 a	0.61±0.02 e
	Wet control	18.10±0.65 a	6.70±0.67 d	1.68±0.06 a	0.53±0.03 a	0.21±0.03 ab	0.04±0.01	0.01±0.00 abc	41.64±0.55 a	-18.39±0.54 b	21.51±0.52 ab	0.61±0.02 e
	LSD $_{(0.05)}$	3.11**	2.27*	0.54**	0.16**	0.09**	0.07ns	0.02**	9.27**	3.92**	4.39*	0.21**
	Dry+1h+0.5m	11.10±0.39 ab	4.46±0.42 de	1.08±0.06 ab	0.34±0.02 bcd	0.08±0.01 bc	0.03±0.01	0.00±0.00 c	29.68±1.89 c	-15.77±1.21 a	0.34±1.20 b	0.88±0.01 b
	Dry+1h+1.0m	10.11±0.14 b	8.06±0.22 a	1.15±0.05 a	0.43±0.03 ab	0.16±0.01 a	0.08±0.02	0.01±0.00 abc	47.16±1.86 a	-21.38±0.51 b	26.98±1.22 ab	0.79±0.01 c
	Wet+1h+0.5m	10.75±0.28 ab	5.46±0.35 bcde	1.07±0.05 ab	0.34±0.02 bcd	0.07±0.01 bcd	0.03±0.01	0.00±0.00 c	32.79±1.46 bc	-15.95±0.27 a	20.81±1.04 b	0.72±0.01 cd
	Wet+1h+1.0m	10.10±0.56 b	7.25±0.47 ab	1.14±0.06 ab	0.40±0.04 abc	0.12±0.02 ab	0.11±0.01	0.02±0.01 a	40.86±0.79 ab	-20.10±0.44 ab	23.60±0.33 ab	0.67±0.01 de
	Dry+2 h+0.5m	11.64±0.24 a	3.32±0.23 e	0.89±0.07 b	0.31±0.02 cde	0.06±0.01 bcd	0.02±0.01	0.00±0.00 c	33.03±4.90 bc	-18.52±0.81 ab	24.06±1.58 ab	1.06±0.03 a
Çermik	Dry+2h+1.0m	8.34±0.19 c	6.78±0.16 abc	1.02±0.03 ab	0.22±0.02 e	0.01±0.00 d	0.03±0.01	0.01±0.00 abc	45.72±1.96 a	-20.33±1.02 ab	26.79±1.18 ab	0.92±0.02 b
	Wet+2h+0.5m	11.09±0.16 ab	4.64±0.35 cde	1.04±0.03 ab	0.29±0.01 cde	0.05±0.01 bcd	0.05±0.01	0.00±0.00 c	33.91±1.69 bc	-16.72±0.65 ab	22.14±1.03 ab	1.02±0.03 a
	Wet+2 h+1.0m	8.41±0.12 c	6.78±0.26 abc	1.17±0.02 a	0.27±0.01 de	0.04±0.02 cd	0.04±0.01	0.01±0.00 abc	42.35±1.32 ab	-20.55±0.49 ab	25.80±1.74 ab	0.72±0.01 cd
	Dry control	10.98±0.32 ab	6.23±0.80 abcd	1.04±0.08 ab	0.39±0.03abcd	0.12±0.02 ab	0.02±0.01	0.01±0.00 bc	42.95±1.19 ab	-18.05±2.47 ab	25.71±1.30 ab	0.62±0.01 ef
	Wet control	11.94±0.20 a	6.68±0.74 abc	1.20±0.04 a	0.50±0.02 a	0.18±0.02 a	0.03±0.01	0.02±0.00 ab	46.04±2.13 a	-19.81±0.51 ab	28.69±2.29 a	0.57±0.02 f
	LSD $_{(0.05)}$	2.23**	2.96**	0.28**	0.16**	0.10**	0.12ns	0.02**	11.71**	4.57**	15.71**	0.09**

*, **Significant at 0.05 and 0.01 levels, respectively. ns: non-significant. Levels not connected by same letter are significantly different
Wet: PRİMİNG; Dry: NON-PRİİMİNG

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Root length differently changed by UV-C treatments. In Kandil variety, root length increased in priming + 1 h + 1.0 m treatment (7.17 cm). Root length was increased in priming + 1 h + 0.5 m in Üçburun variety (9.57 cm), and increased in non-priming + 1 h + 1.0 m treatments (8.06 cm). Similarly, Canbay and Polat (2019) also reported that high doses of UV-B treatments reduced root length in vegetable seedlings.

Root diameter was higher in priming + 1 h + 1.0 m treatment in Kandil (1.65 mm) than other treatments, and the lowest value was obtained from non-priming + 2 h + 0.5 m treatment (1.06 mm). In the Üçburun variety, root diameter increased in priming + 2 h + 1.0 m (1.69 mm), followed by priming control (1.68 mm), non-priming + 2 h + 1.0 m (1.65 mm), and priming + 1 h + 1.0 m (1.58 mm) treatments.

The effect of UV irradiation was significant for plant fresh weight of all three pepper varieties. In Kandil variety, the highest plant fresh weight was obtained from priming + 2 h + 1.0 m treatment (0.47 g), and the lowest value obtained from priming + 2 h + 1.0 m (0.23 g). In Üçburun variety, plant fresh weight increased by priming control (0.53 g), and reduced by priming + 2 h + 0.5 m (0.21 g) treatments. Plant fresh weight of Çermik variety was higher in priming control (0.50 g), and reduced by non-priming + 2 h + 1.0 m (0.22 g).

When the effect of UV radiation on root fresh weight was examined, the effect of UV radiation on all three pepper seeds was statistically significant. The highest root fresh weight was in the control group of dry seeds of Üçburun (0.24 g) and Kandil (0.20 g), and priming control of Çermik (0.18 g) variety. The lowest root weight was recorded in the seedlings of Çermik variety non-priming + 2 h + 1.0 m treatment (0.01 g). Canbay and Polat (2019) reported that plant and root weights decreased with increasing UV doses in the vegetable seedling.

The effect of UV radiation on the plant dry weight of seedlings was not significant in Üçburun and Çermik varieties, while it was significant in Kandil variety ($P \leq 0.01$). The highest plant dry weight was of 0.18 g in non-priming + 1 h + 1.0 m treatment of Kandil variety. The dry plant weights ranged from 0.2 to 0.3 g in other treatments. Lee et al. (2014) reported that the dry matter decreased by UV irradiation. Root dry weight increased in non-priming + 1 h + 1.0 m (0.02 g), priming + 2 h + 1.0 m (0.02 g) and priming + 1 h + 1.0 m (0.02 g) treatments in Kandil, Üçburun and Çermike varieties, respectively.

The effects of different levels of UV light on the color values of seedlings were significant for all three pepper varieties. The highest l* value in Kandil variety was obtained from priming + 2 h + 1.0 m (45.95), followed by non-priming + 1 h + 1.0 m (43.23) and priming + 1 h + 1.0 m (41.48). In Üçburun variety, the highest values were recorded in non-priming control (43.73), non-priming + 1 h + 1.0 m (41.91), non-priming control (41.64), priming + 1 h + 0.5 m (40.84) and priming + 2 h + 1.0 m (40.36) treatments, respectively. In Çermik variety, the highest values were obtained in non-priming + 1 h + 1.0 m (47.16) and priming control (46.04), respectively. The highest a* value was obtained in control group of Kandil variety (-15.01), non-priming control of Üçburun variety (-20.63) and priming + 1 h + 0.5 m (-15.95) and non-priming + 1 h + 0.5 m (-15.77) of Çermik variety. Regarding the b* value, the maximum value was in non-priming + 1 h + 1.0 m treatment of Kandil (24.80), non-priming control (24.59) of Üçburun, and priming control of Çermik (28.69) variety (*Table 1*). Some researchers also reported that increasing doses of UV-C reduced in plant chlorophyll, caratenoid, and color values (Cadwel and Britz; 2006; Tabay, 2014; Canbay and Polat, 2019).

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The amount of proline accumulated from plants was changed by UV-C treatments in all pepper varieties ($P \leq 0.01$). In Üçburun variety, the highest proline accumulation of 1.12 µmol g^{-1} was obtained from UV-C treatment non-priming + 2 h + 0.5 m treatment, while the lowest accumulation was in non-priming and priming control groups (0.61). In Kandil variety, proline accumulation was 1.01 1.12 µmol g^{-1} from priming + 2 h + 0.5 m treatment, whereas the highest value was in non-priming + 2 h + 0.5 m treatment (1.06 µmolg^{-1}) and priming + 2 h + 0.5 m (1.02 µmol g^{-1}) treatment of Çermik variety. Some researchers recorded that the antioxidant enzymes and plant secondary metabolites increased in plants exposed to UV-C, therefore plant defense systems activated caused by photobiological stress (Mahdavian et al., 2008; Jiang et al., 2011; Radyukina et al., 2011; Tabay, 2014).

Conclusion

The paper aimed to determine the effects of different doses of UV-C and gamma rays on the morphological features of some pepper varieties. In the study, it was determined that different doses of gamma rays caused variations in all morphological characteristics of mutant plant seedlings. Especially, the high variation was observed in root fresh weight, root dry weight and plant dry weight in pepper seedlings. Additionally, these findings indicated that increasing doses activated the defense system of plants and doses between 200 and 300 Gy resulted in significant differences. Especially, UV-C source at 0.5 and 2 h distance caused changes in many morphological features in pepper seedlings. Finally, UV-C source at 0.5 m distance and 200-300 Gy caused higher genetic variations than other treatments in pepper varieties. In the future, it is thought that combinations of these gamma and UV-C sources, as well as the mutagens studied, may produce changes in target traits in pepper. These gamma and UV-C sources and their combinations may be used by future studies for the desired features and genetic diversity in pepper.

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