

Effect of drought, UV stress, and melatonin treatment on the growth and essential oil composition of *Pelargonium graveolens* plant.

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Abstract

This research has been done at (September 2024-September 2025) from the Department of Protected Cultivation, Zakho Technical Institute at Duhok Polytechnic University, dealt with the effect of drought stress, UV radiation, and melatonin on the growth and physiology of *Pelargonium graveolens* L. Experimental treatments constituting three drought levels (100%, 75%, and 50% field capacity), UV treatments (control, UV-A, UV-B), and melatonin concentrations (0, 100, 150 μ M) were subjected to a factorial RCBD design. Drought adversely affected plant growth and biomass, while UV-A increased the growth index, leaf area, and biomass as compared to UV-B and control treatments. Melatonin, more so at the 100 μ M concentration, significantly improved performance under drought conditions. The optimal growth (266.27 g biomass) was achieved at 50% field capacity with UV-A and 150 μ M melatonin. Increased chlorophyll as well as essential oil content manifested under UV-A and melatonin, suggesting improvement in photosynthesis and secondary metabolism. These results collectively mean that melatonin application and UV-A restriction could mitigate drought stress with consequent improvement in growth and essential oil production from *Pelargonium graveolens* in these semi-arid regions.

Keywords: *Pelargonium graveolens*, drought stress, UV radiation, melatonin, essential oil.

Introduction

Plants like *Pelargonium graveolens* L. flower in hot weather. This is the best-known of the aromatic and medicinal plants that have been cultivated for ages owing to its essential oil value. It consists of major constituents, that is, citronellal, geraniol, and linalool, which are greatly used in cosmetics, perfumery, and medicines. However, abiotic stresses such as drought and ultraviolet (UV) radiation affect the plant growth, physiology, and essential oil biosynthesis to a greater extent, resulting in considerable economic loss [16].

Drought stress is one of the primary limiting factors for *P. graveolens*. It limits photosynthesis, decreases the chlorophyll content, hampers nutrient uptake, and increases the generation of reactive oxygen species (ROS) that causes damage to cellular membranes and metabolic pathways. Drought can, at times, increase the concentration of essential oil per unit weight because of stress-induced secondary metabolism; however, the total oil yield usually declines due to decreased biomass [16].

Ultraviolet (UV) radiation is shorter wavelengths than radiations of visible

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light. The higher energy radiations influence plant growth and secondary metabolism. They are classified according to their wavelength as UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (100-280 nm), which cause varying biological effects on plants, such as *Pelargonium graveolens*. Similarly, exposure to UV radiation especially UV-B, can cause changes in photosynthetic pigments, affect antioxidant enzyme activities, and alter the biosynthesis of essential oils and phenolic compounds. Increased UV exposure may additionally increase the accumulation of secondary metabolites that offer protection; however, prolonged exposure results in oxidative stress and inhibition of growth. Studies emphasize that understanding metabolic shifts induced by UV is necessary for managing aromatic crops like *P. graveolens* under changing climatic conditions [12].

Melatonin (N-acetyl-5methoxytryptamine) has been considered an efficient bio-regulator promoting plant tolerance against various abiotic stresses in several ways. Also, since it scavenges reactive oxygen

species, it acts as a highly powerful antioxidant, thus stimulating the antioxidant enzymes such as catalase, superoxide dismutase, and peroxidases. In aromatic plants, exogenous melatonin has been shown to change growth and photosynthetic efficiency, which in turn helps maintain biosynthesis of essential oils during drought [12, 17].

In light of this and because of the growing incidence of drought and UV stress as a result of climate change, it is imperative to consider the combination of these stresses on *P. graveolens* and also evaluate the potential of melatonin in counteracting these deleterious effects. This study is aimed at assessing the physiological responses, growth performance, and essential oil composition of *Pelargonium graveolens* under drought and UV-A and UV-B stress, either alone or in interaction with melatonin treatment, to unravel some of the key mechanisms involved in stress tolerance and promote their cultivation strategies under adverse environmental conditions.

Material and Methods

Study period and location

The study was from September 2024 until September 2025 in plastic and cabin houses of the Department of Protected Cultivation, Zakho Technical Institute, Duhok Polytechnic University (37.1664° N, 42.6963° E; 473 m altitude). Temperature data were recorded by using a digital thermo-hydrograph [9].

Table (1): Average of maximum and minimum indoor plastic house and cabin house temperature during study years (2024 and 2025).

Temperature (°C)				Months
2024(cabin house)		2024 (plastic house)		
Min.	Max.	Min.	Max.	
40.1C	52.4 C	17.9 C	55.8 C	September
37.6C	51.2C	14.5 C	54.7 C	October
21.7C	33.8 C	6.3 C	37.2 C	November
5.2 C	17.5 C	3.2 C	20.8 C	December
Temperature (°C)				Months
2025 (cabin house)		2025(plastic house)		
Min.	Max.	Min.	Max.	
0.3 c	25.3 c	2.3 c	27.0 c	January
0.7 c	25.8 c	3.2 c	31.3 c	February
8.6 c	28.5 c	9.9 c	44.2 c	March
13.4 c	25.5 c	9.9 c	34.7 c	April

Soil analysis

A number of samples were selected at random from different locations within the pots, ranging in depth from 0 to 30 cm. The samples were allowed to air dry before being sieved through a 2.0 mm sieve to estimate certain physical and chemical characteristics of the soil, as shown in (table 2). The analysis included measurements of pH, electrical conductivity (EC), available nutrients (N,

P, K), calcium carbonate content (CaCO_3), organic matter (O.M), cation exchange capacity (CEC), and soil texture components (clay, silt, sand). Bulk density was also determined to assess soil compaction. All analyses were conducted at the **Soil and Water Science Laboratory, College of Agricultural Engineering Sciences, Duhok University**, following the procedures described by [3].

Table (2): Some physical and chemical characteristics of the soil.

Analysis Report			
Test	Measuring units	Characteristics	#
7.8		pH (1:1)	1
0.76	dS m ⁻¹	EC (1:1)	2
434.5	mg kg ⁻¹	Available N	3
1.5	mg kg ⁻¹	Available P	4
362.5	mg kg ⁻¹	Available K	5
20.88	%	CaCO ₃	6
1.8		O.M	7
23.55	Cmol ₍₊₎ kg ⁻¹	CEC	8
356.5	g kg ⁻¹	Clay	9
295		Silt	10
348.4		Sand	11
Clay loam		Soil texture class	12
1.32	Mg m ⁻³	Bulk density	13

**The analysis was conducted at the soil and water science laboratory, College of Agricultural Engineering Sciences, Duhok University. according to the [3].

Studied Factors and Experimental Design Analysis

Drought stress, UV radiation, and melatonin treatment were the three factors that made up the factorial randomized complete block design (RCBD) under which the experiment was conducted. Drought stress was composed of three field capacity levels (100%, 75%, and 50%). A control treatment of UV and exposures to

UV-A (320-400 nm) and UV-B (280-320 nm) were administered in separate sections of the cabinets after transplanting for a period of 2 weeks under a 14/10 h day-night photoperiod. The melatonin concentrations of 0, 100, and 150 µM in the Tween-20 medium with diluted ethanol as foliar spray treatment were administered. There were 27 treatments (3 × 3 × 3) replicated thrice, resulting in a total of 81 experimental units, each with nine plants by weight. The effects of drought levels were controlled using a weighing method by [19], while data obtained were analysed using SAS (2010) with Duncan's multiple range test at a 5% level of significance [4].

The FC percentage will have calculated using the following equation:

$$FC (\%) = [(Wet\ soil\ weight - Dry\ soil\ weight) / Dry\ soil\ weight] \times 100$$

The water amount store under FC conditions will estimated after deducting the soil dry weight and the weight of the pots.

Plant Material and Propagation Techniques:

One-year-old seedlings were obtained from the Duhok nursery *Pelargonium graveolens* seedlings (≈ 50 cm high) and transplanted into 27 cm pots filled with loamy-clay soil on September 15. The plants were pruned to the same height by removing side branches and shoot tips. They were first kept in a plastic house (from September 15 to October 15, 2024), and then 72 pots were moved to the cabin house for UV treatments. The plants routinely received weeding, and mulch was used to reduce evaporation and weed growth, white polyethylene covers were also used on cold days for plant protection.

Characteristic	Measurement Method	Source / Reference
Total Anthocyanin	Spectrophotometry	[13,22]
Growth parameters (height, shoot number)	Direct measurement with ruler / counting	[11]
Leaf area	Digital plan meter or image analysis	[20]
Chlorophyll content	SPAD meter or acetone extraction	[13]
Biomass (fresh and dry weight)	Weighing after harvesting and oven-drying	[15]

Growth and Herb Yield Determination

Plant Growth Index (cm³):

Which were calculated according to [11] by the following formula: Growth index (cm³) = $3.14 [1/2 \times (\text{less width} + \text{large width}) / 2]^2 \times \text{plant height}$.

Leaf surface area measurement (cm²)

To determine the leaf area, two leaves at fully expanded were taken from each experimental unit in the different area and the date of collecting samples.

Leaves were randomly collected from all sides of plants; the leaves were picked up in 15th April 2025. Then the leaf areas estimated by (ImageJ 1.52a) software according to [20] from images taken with a camera phone and ImageJ program uses the color ratios of each pixel to distinguish leaves and calibration areas from their background and compares leaf pixel counts to a red calibration area to eliminate the need for camera distance calculations or put a manual ruler scale for measurements [7].

Fresh and dry weight of vegetative growth (g):

Two plants from each treatment were removed from the soil surface, cleaned, and their fresh weight was recorded. They were then dried in an electric oven at 65 to 70 degrees Celsius until their weight remained constant, and the dry weight was recorded using a metallic digital scale [15].

Percentage of dry materials.

The percentage of dry matter is measured according to the following equation [8].

$$\text{Leaf dry matter} = \frac{\text{Leaf dry weight}}{\text{Leaf fresh weight}} * 100$$

Chemicals parameter

Assessment of Chlorophyll Pigment

Chlorophyll pigments were determined following the method described by [1,13,22]. For each transplant, 5–10 leaves were collected, mixed, and transferred in polyethylene bags to the laboratory. A 0.5 g sample of fresh leaves was extracted in 95% ethanol in successive steps over four days to reach a final extract volume of 100 mL.

Absorbance of the ethanol extract was measured using a UV-Vis spectrophotometer at 665 nm (Chlorophyll a), 649 nm (Chlorophyll b), 480 nm (total carotenoids), and 520 nm (total anthocyanin). Chlorophyll concentrations were calculated using standard equations:

$$\text{Chl b (mg/L)} = 27.43 \times A_{649} - 8.12 \times A_{665}$$

$$\text{Chl b (mg/L)} = 27.43 \times A_{649} - 8.12 \times A_{665}$$

$$\text{Chl a (mg/g FW)} = \frac{\text{Chl a (mg/L)}}{0.1} \times 0.5$$

$$\text{Chl a (mg/g FW)} = 0.5 \times \text{Chl a (mg/L)} \times 0.1$$

This method provided reliable estimates of chlorophyll a, chlorophyll b, total carotenoids, and total anthocyanin in fresh leaf tissue.

Essential Oil Determination

The essential oil content of (geranium) will be ascertained by drying it under normal weather and shade conditions. The Clevenger Apparatus machine will be used to check the percentage of essential oil in the collected samples. To do this, various dried plant samples are ground into small pieces using a laboratory mill (for better essential oil extraction), and 100 grimes of

each sample are weighed for essential oil extraction using an accurate digital V level. The samples are then transferred to a balloon

Following their separation, the essential oils were dehydrated using sodium sulphate and kept in special jars at 4 ° C in a dark location until they could be analysed and extracted three times. GC-FID and GC-MS will be used to analyse essential oils. [2]

Volatile Oil percentage = weight volatile oil / weight of 100 gm fresh plant material × 100. Then the amount was calculated by using the following formula:

Amount of Volatile Oil gm/plant = Total weight of first harvest × Percentage of volatile oil.

RESULTS

Plant Growth Index (cm³)

The data in Table (1) illustrate the Drought stress had no significant increase the value. The UV light had a significant influence at (30200cm³). As Melatonin had shown in the table there is no significant different between treatment. The interaction between Drought and UV light had significant increase were 75% field capacity with UV-A reached to (43794 cm³), Then interaction between Drought and Melatonin had a significant increase level of Plant Growth Index in 50% +100 μM to (42336 cm³). Third interaction of UV light with melatonin show that had significant influence reached to (46811 cm³) in UV-A with Melatonin Control. The effect of Plant Growth Index got affected when the plants under control of (50% field capacity + UV Control + 100 μM) raised to (62617cm³), and then decreased to (2131cm³) when field capacity 75% + UV-B + Melatonin Control.

Table (1): Role of melatonin in assessing the impact of drought stress and UV light on plant growth index of *Pelargonium graveolens*.

Leaf surface area measurement (cm²)

The data in table (2), shown Drought stress had a significant influence on leaf surface area in the (18.604 cm²). The UV light no

Drought stress with UV-A The highest leaf surface area (19.604 cm²) Significant differences occurred from the interaction treatments between Drought

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
12752 a	10844 b	9676 abc	6189 abc	16668 abc	0	100%
	15617 ab	11675 abc	13458 abc	20999 abc	UV-A	
	12114 b	10231 abc	10760 abc	15353 abc	UV-B	
19137 a	9747 b	6803 abc	7701 abc	14738 abc	0	75%
	43794 a	25369 abc	46724 abc	59288 ab	UV-A	
	3868 b	4264 bc	5210 bc	2131 c	UV-B	
27409 a	28785 ab	9773 abc	62617 a	13966 abc	0	50%
	29569 ab	6816 abc	21742 abc	60147 ab	UV-A	
	23872 ab	7043 abc	42650 abc	21925 abc	UV-B	
UV Light		10183 a	24527 a	25024 a	Melatonin	
		10527 b	9720 b	17673 ab	100%	Drought stress * Melatonin
		12146 b	19878 ab	25386 ab	75%	
		7877 b	42336 a	32013 ab	50%	
16459 ab	0	13136 b	25502 ab	15124 b	0	UV Light * Melatonin
30200 a	UV-A	14620 b	29040 ab	46811 a	UV-A	
13285 b	UV-B	7179 b	19540 ab	8751 b	UV-B	

significant effected on leaf surface area in the three conditions. Third factor control, UV-A and UV-B as for the effect of spray melatonin also there are no significant effected on leaf surface area in each concentration.

Significant differences were saw in the interaction between the Drought stress and UV light in leaf area character, The interaction treatment between 50% of

stress and melatonin in leaf surface area character, 50% of drought stress with (100µM) concentrations of melatonin spray. The interaction between UV light and melatonin spray had a no significant impact on leaf surface area. The interaction treatments among the three factors indicated to significant differences were 50% + UV-B and control of melatonin gave the highest leaf surface area (20.798 cm²) which had the lower value (9.406 cm²) in the 75% + UV-B and 150 µM.

Table (2): Role of melatonin in assessing the impact of drought stress and UV light on the Leaf surface area of *Pelargonium graveolens*.

Drought stress	UV Light	Melatonin			Drought stress* UV Light	Drought stress
		0	100	150		
100%	0	10.866 abc	11.899 abc	14.910 abc	12.558 cd	12.694 b
	UV-A	11.353 abc	14.861 abc	16.104 abc	14.106 bcd	
	UV-B	12.348 abc	9.891 bc	12.017 abc	12.558 d	
75%	0	15.028 abc	11.165 abc	12.835 abc	13.009 bcd	13.264 b
	UV-A	11.713 abc	14.739 abc	12.699 abc	13.050 bcd	
	UV-B	11.997 abc	19.793 ab	9.406 bc	13.732 bcd	
50%	0	14.871 abc	18.980 abc	19.802 ab	17.884 abc	18.604 a
	UV-A	19.912 ab	19.842 ab	19.058 abc	19.604 a	
	UV-B	20.798 a	17.353 abc	16.822 abc	18.324 ab	
Melatonin		14.321 a	15.392 a	14.850 a	UV Light	
Drought stress * Melatonin	100%	11.522 b	12.217 b	14.344 ab		
	75%	12.913 b	15.232 ab	11.647 b		
	50%	18.527 a	18.725 a	18.561 a		
UV Light * Melatonin	0	13.588 a	14.015 a	15.849 a	0	14.484 a
	UV-A	14.326 a	16.481 a	15.954 a	UV-A	15.587 a
	UV-B	15.048 a	15.679 a	12.748 a	UV-B	14.492 a

Fresh and dry weight of vegetative growth (g):

The results in tables (3), (4) indicate that Drought had a significant effect to fresh weight of vegetative growth in the 50% (170.21 g), also Drought had a significant effect to dry weight of vegetative growth in the 50% (170.21 g). UV light had a significant impact on fresh weight of vegetative growth in the (136.79 g) were in control condition, but on dry weight of vegetative growth had a no significant effect in their weight. Melatonin spray we saw no significant effect on fresh and dry weight of vegetative growth.

The result we obtained in the interaction between Drought stress and UV light in fresh and dry weight character, in case of fresh weight that show had a significant effect in the (216.65 g) and in dry weight in the (216.65 g) both of them with 50% + UV-A. The interaction between Drought stress and Melatonin in fresh and dry weight of vegetative growth character, in fresh and dry weight had a significant effect in the (197.35 g). The interaction between UV light and Melatonin in fresh and dry weight of vegetative growth character, both of them had a no significant influence of the weight in fresh and dry vegetative growth.

The interaction treatments among the three factors indicated to significant influence of

the weight in fresh in the (266.27g) were 50% + UV-A + 150 µM, in dry weight same of the fresh weight had a significant influence in the (266.27g).

Table (3) Role of melatonin in assessing the impact of drought stress and UV light on the

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
26.84 b	38.29 c	37.63 d	35.13 d	42.10 d	0	100%
	20.88 c	20.83 d	23.70 d	18.10 d	UV-A	
	21.36 c	19.80 d	25.27 d	19.00 d	UV-B	
14.34 b	19.38 c	7.77 d	18.30 d	32.07 d	0	75%
	12.02 c	9.27 d	17.53 d	9.27 d	UV-A	
	11.63 c	7.33 d	11.33 d	16.23 d	UV-B	
170.21 a	175.88 ab	185.76 abc	218.83 abc	123.04 bcd	0	50%
	216.65 a	266.27 a	252.02 ab	131.66 abc	UV-A	
	118.08 b	140.02 abcd	114.43 cd	99.80 cd	UV-B	
UV Light		77.19 a	79.62 a	54.59 a	Melatonin	
		26.09 c	28.03 c	26.40 c	100%	Drought stress * Melatonin
		8.12 c	15.72 c	19.19 c	75%	
		197.35 a	195.10 a	118.17 b	50%	
77.85 a	0	77.05 a	90.76 a	65.74 a	0	UV Light * Melatonin
83.18 a	UV-A	98.79 a	97.75 a	53.01 a	UV-A	
50.36 a	UV-B	55.72 a	50.34 a	45.01 a	UV-B	

Table (4) Role of melatonin in assessing the impact of drought stress and UV light on the Dry weight of *Pelargonium graveolens*.

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
102.29 b	148.67 abc	140.67 abcde	147.60 abcde	157.75 abcde	0	100%
	75.52 cd	76.10 cde	83.01 cde	67.46 de	UV-A	
	82.69 cd	70.69 de	91.34 cde	86.04 cde	UV-B	
65.65 b	85.81 cd	28.29 e	108.38 cde	120.76 bcde	0	75%
	57.09 d	30.48 e	101.26 cde	39.53 e	UV-A	
	54.07 d	29.58 e	66.29 de	66.34 de	UV-B	
170.21 a	175.88 ab	185.76 abcd	218.83 abc	99.80 cde	0	50%
	216.65 a	266.27 a	252.02 ab	131.66 abcde	UV-A	
	118.08 bcd	140.02 abcde	114.43 bcde	123.04 bcde	UV-B	
UV Light		107.54 a	131.46 a	99.15 a	Melatonin	
		95.82 bc	107.32 b	103.75 bc	100%	Drought stress * Melatonin
		29.45 c	91.97 bc	75.54 bc	75%	
		197.35 a	195.10 a	118.17 b	50%	
136.79 a	0	118.24 a	158.27 a	133.85 a	0	UV Light * Melatonin

Percentage of dry materials (%).

Analysis of the data reveals that in table (5) the Drought stress shown significant different in Percentage of dry materials in the (26.421 %) with 100% field capacity. UV light conditions has no significant different in Percentage of dry materials and all conditions same effect to the dry materials. Melatonin spray has significant influence to Percentage of dry materials character in the (26.646 %). The effect of Drought stress and UV light together shown significant different the highest

level in the(27.328 %) were control field capacity with UV-A.

Interaction between factors Drought stress and Melatonin indicate that had a significant different in the (29.303%). Significant differences occurred from the interaction treatments between UV light and Melatonin in the (27.776%) were UV-A with 150 µM of Melatonin spray. A three-factor interaction (Drought stress *UV light *Melatonin) was found to be statistically different to Percentage of dry materials character, The interaction between treatment 75% + UV-A + 150 µM in the highest level (31.875%)

Table (5) Role of melatonin in assessing the impact of drought stress and UV light on the Dry materials of *Pelargonium graveolens*.

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
26.421 a	25.811 ab	27.135 abcd	23.543abcdefg	26.757 abcd	0	100%
	27.328 a	26.870 abcd	28.403 ab	26.713 abcde	UV-A	
	26.122 ab	28.461 ab	28.218 abc	21.687 bcd	UV-B	
24.079 ab	24.620 ab	29.913 ab	17.699 efg	26.249 abcdef	0	75%
	24.303 ab	31.875 a	17.499 fg	23.534 abcdefg	UV-A	
	23.313 ab	26.121 abcdefg	18.610 defg	25.209 abcdefg	UV-B	
23.631 b	21.837 b	25.597 abcdefg	17.132 g	22.781 abcdefg	0	50%
	26.304 ab	24.585 abcdefg	25.750abcdefg	28.579 ab	UV-A	
	22.753 ab	19.257 cdefg	24.504abcdefg	24.497 abcdefg	UV-B	
UV Light		26.646 a	22.373 b	25.112 a	Melatonin	Drought stress * Melatonin
		27.488 ab	26.721 abc	25.052 abc	100%	
		29.303 a	17.936 d	24.997 abc	75%	
		23.146 bc	22.462 c	25.286 abc	50%	
24.090 a	0	27.548 a	19.458 b	25.262 a	0	UV Light * Melatonin
25.979 a	UV-A	27.776 a	23.884 ab	26.275 a	UV-A	
24.063 a	UV-B	24.613 a	23.777 ab	23.798 ab	UV-B	

Assessment of Chlorophyll (A) nm.

The results in Table (6) clarified that Drought stress on the *Pelargonium graveolens* had a no significant effect in

the chlorophyll (A). In addition, effect UV cause caused a significantly increased in chlorophyll (A) to reach (0.29904 nm) compared with (0.28070nm) for control, Whereas, Melatonin spray to the plant in concentration 100 μ M significant influence in chlorophyll (A) increase level to (0.32189nm) compared to twice concentration. The interaction between the Drought stress and UV light shown had a significantly increased in chlorophyll (A) in 100% field capacity with UV-B to reach (0.30811nm). Additionally, the level chlorophyll (A) significant increase in both

75% and 50% with 100 μM reach to (0.33644 nm) compare to other treatments. The three interaction between the UV light and Melatonin indicated that there significantly increased in the (0.35356 nm) chlorophyll (A). The interaction between

triple factors Drought stress, UV light and Melatonin spray had a significantly increased in chlorophyll (A) to reach (0.37300nm) were both 75%, 50% field capacity + UV-B + 100 μM Melatonin concentration.

Table (6) Role of melatonin in assessing the impact of drought stress and UV light on the Chlorophyll(A) on leaves of *Pelargonium graveolens*.

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
0.28389 a	0.27944 ab	0.27333 cdef	0.28467 bcdef	0.28033 bcdef	0	100%
	0.26411 b	0.29267 bcde	0.27900 bcdef	0.22067 ef	UV-A	
	0.30811 a	0.30067 abcd	0.31467 abc	0.30900 abcd	UV-B	
0.27898 a	0.28133 ab	0.28000 bcdef	0.35567 ab	0.20833 f	0	75%
	0.26111 b	0.26500 cedf	0.28067 bcdef	0.23767 cdef	UV-A	
	0.29450 ab	0.27717 cdef	0.37300 a	0.23333 def	UV-B	
0.27898 a	0.28133 ab	0.28000 bcdef	0.35567 ab	0.20833 f	0	50%
	0.26111 b	0.26500 cedf	0.28067 bcdef	0.23767 cedf	UV-A	
	0.29450 ab	0.27717 cdef	0.37300 a	0.23333 def	UV-B	
UV Light		0.27900 b	0.32189 a	0.24096 c	Melatonin	
		0.28889 b	0.29278 b	0.27000 b	100%	Drought stress * Melatonin
		0.27406 b	0.33644 a	0.22644 c	75%	
		0.28889 b	0.33644 a	0.22644 c	50%	
0.28070 ab	0	0.27778 b	0.33200 a	0.23233 c	0	UV Light * Melatonin
0.26211 b	UV-A	0.27422 b	0.28011 b	0.23233 c	UV-A	
0.29904 a	UV-B	0.28500 b	0.35356 a	0.25856 bc	UV-B	

Assessment of Chlorophyll (B) nm.

Analysis of the data reveals that in table (7) Drought stress had a no significant effect to

the Chlorophyll (B). But UV light shown had a significantly increased in chlorophyll (B) in condition UV-B (0.098056 nm). Also Melatonin spray to the plant in concentration 100 µM significant influence in chlorophyll (B) increase level to (0.096519 nm). The interaction between two factors Drought stress and UV light had a significantly increased in

(0.10756nm) chlorophyll (B) were UV-B with 50% of field capacity. The factor Drought stress and Melatonin together shown result in 75% filed capacity and 100 µM increase level of chlorophyll (B) (0.11178 nm). The third interaction between UV light and Melatonin we can found also in treatment of UV-B and 100 µM increase level of chlorophyll (B) (0.10672 nm). A three-factor interaction (Drought stress *UV light *Melatonin) was found to be statistically effect to the chlorophyll (B) character in the (0.14567nm).

Table (7) Role of melatonin in assessing the impact of drought stress and UV light on the Chlorophyll(B) on leaves of *Pelargonium graveolens*.

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
0.087426 a	0.08533 abc	0.08400 bcd	0.08700 bcd	0.08500 bcd	0	100%
	0.07967 bc	0.09633 bcd	0.08067 bcd	0.06200 d	UV-A	
	0.09728 ab	0.09650 bcd	0.09383 bcd	0.10150 bcd	UV-B	
0.085833 a	0.09461 ab	0.07133 cd	0.14567 a	0.06067 d	0	75%
	0.07356 bc	0.07600 bcd	0.07667 bcd	0.06800 dc	UV-A	
	0.08933 abc	0.08367 bcd	0.11300 abc	0.07750 bcd	UV-B	
0.087593 a	0.06644c	0.06367 d	0.07100 cd	0.06467 d	0	50%
	0.08878 abc	0.10017 bcd	0.08750 bcd	0.07867 bcd	UV-A	
	0.10756 a	0.09000 bcd	0.11333 abc	0.11933 ab	UV-B	
UV Light		0.085315 ab	0.096519 a	0.079019 b	Melatonin	
		0.09228 ab	0.08717 ab	0.08283 b	100%	Drought stress * Melatonin
		0.07906 b	0.11178 a	0.06667 b	75%	
		0.08461 b	0.09061 ab	0.08756 ab	50%	
0.082130 b	0	0.07506 bc	0.10122 a	0.07011 c	0	UV Light * Melatonin
0.080667	UV-A	0.09083	0.08161	0.06956 c	UV-A	Melatonin

b		abc	abc			
0.098056 a	UV-B	0.09006 abc	0.10672 a	0.09739 ab	UV-B	

Assessment of Total Chlorophyll.

The results in Table (8) clarified that Drought stress shown that there is no significant different in all treatment of this factor of Total Chlorophyll. UV light in this data shown had a significant effect Total Chlorophyll character in the (0.39676 nm).

Melatonin in this parameter shown had a significant increase level of Total

Chlorophyll in 100 μM (0.39383nm). The interaction between Drought stress and UV light had a significant effect Total Chlorophyll character in the (0.41150 nm). Additionally, effect twice factor Drought stress and Melatonin together shown that had a significant influence to charterer in the (0.44822 nm). Third interaction between UV light and Melatonin in UV-B and 100 μM increase the level Total Chlorophyll character in the (0.43233 nm). The triple interactions Drought stress, UV light and Melatonin factors indicated that the plants with 75% + no UV light + 100 μM gave the highest value of Total Chlorophyll reaching to (0.50133 nm)

Table (8) Role of melatonin in assessing the impact of drought stress and UV light on the Total Chlorophyll on leaves of *Pelargonium graveolens*.

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
0.36109 a	0.34522 abc	0.29867 de	0.37167 bcde	0.36533 bcde	0	100%
	0.34311 abc	0.38700 abcde	0.35967 bcde	0.28267 de	UV-A	
	0.39494 ab	0.39717 abcde	0.40750 abcd	0.38017 abcde	UV-B	
0.36481 a	0.37594 ab	0.35750 bcde	0.50133 a	0.26900 e	0	75%
	0.33467 bc	0.34100 dce	0.35733 bcde	0.30567 de	UV-A	
	0.38383 ab	0.36083 bcde	0.48600 ab	0.30467 de	UV-B	
0.35430 a	0.28933 c	0.28233 de	0.29867 de	0.28700 de	0	50%
	0.36206 ab	0.39667 abcde	0.35883 bcde	0.33067 cde	UV-A	
	0.41150 a	0.38867 abcde	0.40350 abcd	0.44233 abc	UV-B	
UV Light		0.35665 b	0.39383 a	0.32972 b	Melatonin	
		0.36094 bc	0.37961 b	0.34272 bc	100%	Drought stress * Melatonin
		0.35311 bc	0.44822 a	0.29311 c	75%	
		0.35589 bc	0.35367 bc	0.35333 bc	50%	
0.33683 b	0	0.31283 c	0.39056 ab	0.30711 c	0	UV Light * Melatonin
0.34661 b	UV-A	0.37489 abc	0.35861 bc	0.30633 c	UV-A	
0.39676 a	UV-B	0.38222 ab	0.43233 a	0.37572 abc	UV-B	

Assessment of Total Carotene.

The results in Table (9) indicated that *Pelargonium graveolens* We applied Drought stress in three different type of field capacity had a significant effect in the Total Carotene in the (0.28728nm) were 100% field capacity. When applied UV light in three different conditions but we show no significant effect in the Total Carotene in this plant and all of them same

to each other. Moreover, Melatonin spray also same to UV light in effect on this plant had a no significant effect in the Total Carotene. The results of the interaction between the Drought stress and UV light increase significant value in

100% field capacity with UV-B reached to (0.31372nm). In addition to that, interaction between the Drought stress and Melatonin indicated there are no significant different between each

treatment. The third dual interactions between the UV light and Melatonin same to the before interaction of Drought stress and Melatonin no significant different between each treatment. The triple interactions Drought stress, UV light and Melatonin indicated in 75% + UV-B + 100 µM gave the highest value in the

(0.33600nm) compare were 50% + UV-A +100 µM gave the lowest value.

Table (9) Role of melatonin in assessing the impact of drought stress and UV light on the Total Carotene on leaves of *Pelargonium graveolens*.

Drought stress	UV Light	Melatonin			Drought stress* UV Light	Drought stress
		0	100	150		
100%	0	0.27100 ab	0.28467 ab	0.26800 ab	0.27456 ab	0.28728 a
	UV-A	0.21900 ab	0.28200 ab	0.31967 ab	0.27356 ab	
	UV-B	0.32250 ab	0.32100 ab	0.29767 ab	0.31372 a	
75%	0	0.23433 ab	0.32100 ab	0.26150 ab	0.27217 ab	0.26944 ab
	UV-A	0.27467 ab	0.21033 ab	0.26450 ab	0.24983 ab	
	UV-B	0.25133 ab	0.33600 a	0.27167 ab	0.28633 ab	
50%	0	0.22400 ab	0.22067 ab	0.21433 ab	0.21967 b	0.23802 b
	UV-A	0.24700 ab	0.19400 b	0.24750 ab	0.22950 b	
	UV-B	0.25517 ab	0.24717 ab	0.29233 ab	0.26489 ab	
Melatonin		0.25544 a	0.26850 a	0.27080 a	UV Light	
Drought stress * Melatonin	100%	0.27083 a	0.29589 a	0.29511 a		
	75%	0.25344 a	0.28900 a	0.26589 a		
	50%	0.24206 a	0.22061 a	0.25139 a		
UV Light * Melatonin	0	0.24311 a	0.27533 a	0.24794 a	0	0.25546 a
	UV-A	0.24689 a	0.22878 a	0.27722 a	UV-A	0.25096 a
	UV-B	0.27633 a	0.30139 a	0.28722 a	UV-B	0.28831 a

Assessment of Total Anthocyanin.

The results in Table (10) indicated that *Pelargonium graveolens* had a no significant effect by Drought stress. UV light, were plant under UV-B condition had a significant effect increase the level of Total Anthocyanin reached to (0.051019nm) compare were plant under the Control condition. Also were *Pelargonium graveolens* spray with melatonin had a no significant effect to

Total Anthocyanin. The interaction between factors Drought stress and UV light had a significant effect increase the

level of Total Anthocyanin reached to (0.060444nm) were plant under 50% field

capacity and UV-B conditions. Additionally, interaction between Drought stress and Melatonin had a significant effect increase reached to (0.054000nm). three interactions between UV light and Melatonin had a significant effect were plant under UV-B with 100 μ M. Triple interactions between Drought stress, UV

light and Melatonin had a significant effect were 50% + UV-B + 100 μ M reached to (0.06833 nm).

Table (10) Role of melatonin in assessing the impact of drought stress and UV light on the total anthocyanin on leaves of *Pelargonium graveolens*.

Drought stress	Drought stress* UV Light	Melatonin			UV Light	Drought stress
		150	100	0		
0.045519 a	0.047667 ab	0.04233 abc	0.04933 abc	0.05133 abc	0	100%
	0.044333 bc	0.04800 abc	0.04267 abc	0.04233 abc	UV-A	
	0.044556 bc	0.04133 abc	0.04667 abc	0.04567 abc	UV-B	
0.045630 a	0.046167 ab	0.05017 abc	0.06000 ab	0.02833 c	0	75%
	0.042667 bc	0.04500 abc	0.04200 abc	0.04100 abc	UV-A	
	0.048056 ab	0.04650 abc	0.06000 ab	0.03767 bc	UV-B	
0.047278 a	0.031111 c	0.02567 c	0.03100 c	0.03667 bc	0	50%
	0.050278 ab	0.06050 ab	0.03967 bc	0.05067 abc	UV-A	
	0.060444 a	0.04867 abc	0.06833 a	0.06433 ab	UV-B	
UV Light		0.045352 a	0.048852 a	0.044222 a	Melatonin	
		0.043889 ab	0.046222 ab	0.046444 ab	100%	Drought stress * Melatonin
		0.047222 ab	0.054000 a	0.035667 b	75%	
		0.044944 ab	0.046333 ab	0.050556 ab	50%	
0.041648 b	0	0.039389 b	0.046778 ab	0.038778 b	0	UV Light * Melatonin
0.045759ab	UV-A	0.051167 ab	0.041444 b	0.044667 ab	UV-A	
0.051019 a	UV-B	0.045500 ab	0.058333 a	0.049222 ab	UV-B	

4.12 Volatile Oil percentage.

The results in Figure (1) clarified that 50% of field capacity + UVB condition + 100 µM of Melatonin concentration on the *Pelargonium graveolens* had a significant effect to value of Volatile Oil increased to (4.33) compared to the control conditions

of three factors were (2.17). Also were plant

under UVB and 50% of field capacity with control of Melatonin had an increase level Volatile oil we saw Melatonin made a good role same time were twice factors Drought stress and UV light both of them control but Melatonin concentration at

(100,150) increase value of Volatile Oil character, where significance was set at $p \leq 0.05$.

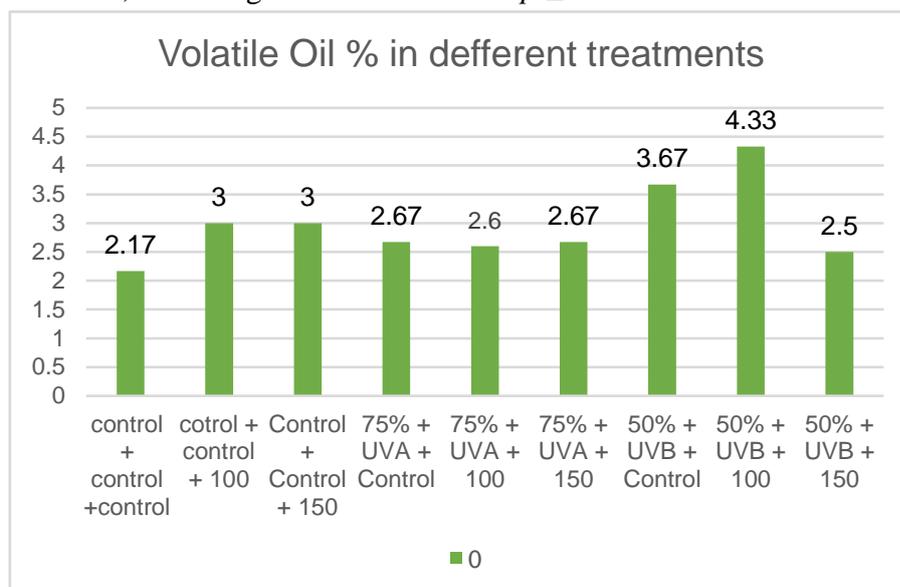


Figure (1): Role of melatonin in assessing the impact of drought stress and UV light on the volatile oil percentage in the leaves of *Pelargonium graveolens*.

Discussion

Drought stress considerably reduced growth, biomass, and leaf area of *Pelargonium graveolens*; whereas, UV-A radiation and exogenous melatonin treatments (especially 100-150 μM) significantly alleviated these adverse effects in terms of chlorophyll content, fresh and dry weight of aerial parts, and yield of essential oils. These findings corroborate several studies indicating that melatonin, as an antioxidant and signalling molecule, stabilizes photosynthetic machinery and enhances drought tolerance [6,21]. However, UV-A could promote some growth and secondary metabolite accumulation, while UV-B induce growth reduction through stress, in line with previous reports on geraniums and other aromatic plants [23]. Our observation of synergisms—best performance under 50% field capacity + UV-A + 150 μM

melatonin—is likely due to the formation of mild stress signals by UV-A that stimulate metabolite synthesis, while melatonin diminishes oxidative damage and maintains physiological functioning [10,24]. This combination encouraged not just vegetative growth but also the yield of essential oil, supporting earlier reports of the effects of UV and melatonin on secondary metabolite accumulation [5,14,18]. A dose-effect and exposure paradigm is detected here, since too much UV-B or an intensifying level of drought stress would suppress growth despite elevated metabolite concentration. Overall, this intentional combination of optimized exposure of UV-A with melatonin application may be a feasible scheme for efficient enhancement of drought resilience and essential oil formation in *Pelargonium graveolens* semi-arid conditions; howbeit, further investigations on oil composition, reactive oxygen species, antioxidant

activity, and gene expression should help

elucidate the underlying mechanisms

Conclusion

Under drought stress, *Pelargonium graveolens* responded positively to melatonin and UV-A treatment. Drought conditions reduced growth and biomass; however, exposure to UV-A and treatment with melatonin (especially at the level of 150 μ M) promoted improvements in plant performance, chlorophyll content, and

essential oil yield. The use of 50% field capacity, UV-A radiation, and melatonin was found to be the best treatment, indicating that using melatonin and UV-A together in semi-arid environments may improve drought tolerance and productivity.

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