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Alterations in Essential Oil Yield and Quality of Geranium Grown in Sandy Soil as Affected by Preharvest Water Stress Levels

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Abstract: The current investigation was conducted during 2022 and 2023 at the experimental research farm of Ali Mubarak EL-Bostan area to quantify the effect of different water stress levels before harvest (during flowering stage) of geranium plant grown in sandy soil on geranium plant growth, its essential oil content and composition when the plant was exposed to six different levels of water stress (100, 70, 60, 50, 40 and 30% of ETo) for four weeks before harvesting between bud initiation and flowering stage. Water stress levels had insignificant alteration on growth characteristics during the last four weeks before harvesting. It could be observed from the obtained results that when geranium plants were subjected to water stress level (50% of ETo) the essential oil content trended to maximize (0.26-0.30%). Also, water stress altered essential oil composition. Water stress level (50% of ETo) increased geraniol and lowered citronellol since increasing water stress accelerated the transformation of hydrocarbons (α-pinene, β-Pinene, Ocimene, limonene and β-Caryophyllene) to their oxygenated constituents, water stress level (50% of ETo) maximized antioxidants content. It could be concluded that water stress at (50% of ETo) for four weeks before harvesting geranium when correctly timed and appropriate level could increase essential oil content and improve its quality.

Key words: Water stress, *Pelargonium graveolens*, flowering stage, oil accumulation.

1. Introduction

Geranium (*Pelargonium graveolones* L.) is one of the most important genus of the family Geraniaceae, several of *Pelargonium* species are cultivated for production of volatile oil (geranium oil) **(Groom, 2012).**

Geranium oil has beneficial properties such as antifungal, antibacterial and antioxidant activities and is used as anti-inflammatory, antiseptic and astringent. Oil is also included in some skin diseases medications to resist fungi or bacteria when used externally, as it is useful in gastric colic, expulsion of gases and bloating. It is also used as a fragrant component in all kinds of cosmetics **(Galea and Hancu, 2014 and Abdel-Ghany *et al.*, 2020).**

The rose scent of geranium oil is a combination of citronellol, geraniol, linalool, geranyl acetate, menthone, limonene, geranyl butyrate, myrcene and pinene **(Clarke, 2009).** Citronellol and geraniol ratio (C:G) are usually indicator to geranium oil quality. The C:G ratio of one to three is acceptable. **(Motso *et al*., 2006).**

Aromatic components biosynthesis, *i.e.,* essential oil (EO), produce in the leaves during flowering stage **Abdi *et al.*, (2019).** The highest volatile components biosynthesis rate in the flowering stage is strongly linked to the high production of biomass and oil content at this stage **(Toncer *et al.*, 2017).** The low amount of volatile components biosynthesis during the vegetative stage may be due to partial inactivation of the enzymes necessary for the biosynthesis of some components. Essential oil content decreased during developmental phases due to the accumulation of photosynthetic products in the endosperm. **(Ozcan and Chalchat, 2006).**

Studies have shown that, despite the detrimental impacts of water stress, produce quality can benefit from it by triggering the creation of secondary metabolites **(Sangwan *et al.*, 2001).** Plants stressed by water stress have potential sources of antioxidants such as polyphenols. Consequently, it can be hypothesized that an increase in polyphenols could be obtained by stress-tolerant species **(De Abreu and Mazzafera, 2005).**

Managing the production of medicinal and aromatic plants under water deficit differs from that of other crops. Enhancing the synthesis of active components is the main objective here, in addition to maximizing the yield of the plant's above-ground parts. Water stress can paradoxically increase the amounts of secondary metabolites in certain aromatic and medicinal plants., if applied at the appropriate physiological stage and with the degree of stress that stimulates the formation of volatile oil **(Sangwan *et al.*, 2001).**

However, the level and duration of water stress have a beneficial impact on some components in aromatic and medicinal plants. Previous research has shown that systems where plants have less access to water, it can be increased in essential oil quality and quantity in plants. **(Alvarenga *et al.*,2011).**

Even though there are a number of studies with the effect of full irrigation and different water deficit stress levels on geranium plant development and essential oil content, studies on the influence of water stress on essential oil production and its composition during flowering stage is poorly understood. The objective of this study is to develop the appropriate irrigation level of geranium during flowering stage grown sandy soil to increase the essential oil accumulation and its active ingredients.

2. Material and Methods

This study was carried out at the Experimental Farm of South Tahrir Horticulture Research Station, at Ali Mubarak Farm, EL-Bostan Area, Egypt, (Longitude 30°42'36.00" E, Latitude 30°34'12.00" N), during the two successive seasons of 2022 and 2023 to evaluate the effect of different water stress levels during flowering bud initiation stage on essential oil productivity and its quality in geranium (*Pelargonium graveolens*) grown in sandy soil.

The physical and chemical characteristics of the soil of the experimental field were determined according to **Page *et al.* (1982)** and are shown in Table (1).

On 15^{th} February 2022, and 2023, rooted terminal stem cuttings of *Pelargonium graveolens* L. were planted. Planting was done in rows 75 cm apart and with 50 cm between hills using a drip irrigation system. The drip irrigation system utilized in the present study comprised of a 32 mm main supply pipeline made of PE and a 25 mm sub-main line made of PE. The drip laterals were made of 16 mm-diameter polyethylene, and the emitters were placed 25 cm apart inline, with an actual discharge rate of 4 liters per hour.

Table (1). Chemical and physical analyses of the soil at experimental site

Physical properties	
Texture	Sandy
Sand (%)	92.9
Silt (%)	2.7
Clay (%)	4.4
Field Capacity, (%)	13.0
Wilting Point, (%)	4.6
Available water, (%)	8.4
Bulk density (t m^{-3})	1.69
Chemical properties	
$EC_{1:5}$ (dS m^{-1})	0.45
pH (1:2.5)	8.60
Total $CaCO_3$ (%)	7.00

Irrigation water stress during flowering stage grown in sandy soil were applied 4 weeks before the first cut during the initiation of flower buds up the flowering (during April) and 4 weeks before the second cut (during September) as follows: 100 %, 70%, 60%, 50%, 40% and 30 % of ET_O (based on evaporation data). The value of ETo was calculated using reference evapotranspiration data from the Tahrir Region of Egypt. The weather data are displayed in Table (2). The layout of experiment was a complete randomized block design (6 treatments) with three replicates.

Compost at rate of 10 m^3 was added during soil preparation. The recommended dose of nitrogen, phosphorus and potassium fertilizers were added at a rate of 400 kg/fed as ammonium sulphate (20.5% N), 75 l/fed as phosphoric acid (85% H_3PO_4) and 100 kg/fed as potassium sulfate (48% K_2O) through fertigation and were given to the plants starting from the 3 week after transplanting. The Egyptian Ministry of Agriculture recommendations were followed in all agricultural practices.

Table (2). The monthly average values of reference evapotranspiration (ETo mm/ day) of experimental site (El-Bostan area, Ali Mubark Farm at South Tahrir Region Egypt weather data) for both planting seasons.

Seasons	February	March	April	May	June	July	August	September	October
2022	3.22	4.15	4.34	6.1	6.32	6.44	6.51	5.25	4.09
2023	3.48	4.48	4.69	6.59	6.83	6.96	7.03	6.67	4.42

2.1. Crop-water relationships

i. Reference Evapotranspiration (ETo)

Using the class A pan evaporation method **(Doorenbos and Kassam, 1986)**, the ETo was calculated using the following equation:

$$ETo = Epan \times Kpan$$

Where: ET_o: reference evapotranspiration (mm d^{-1}), Epan: daily measured pan evaporation (mm d^{-1}), Kpan: A value of 0.75 was used for the experimental site according to the climatic local condition **(FAO, 1970)**.

ii. Applied Irrigation Water (AIW):

As stated by **Vermeirer and Topling (1984),** the following equation was used to compute the amount of applied irrigation water.

$$AIW = (ETo \times Kr \times I/Ea) + LR$$

Where: **AIW**: depth of applied irrigation water (mm),

ET_o: reference evapotranspiration (mmd^{-1}),

Kr: evaporation reduction coefficient, depend on ground cover, a value of 1.0 was used (where the spacing between drip lines is less than 1.8m, FAO, 1970).

I: irrigation intervals (days),

Ea: irrigation efficiency of the drip irrigation system, an average value of 0.8 was used.

LR: leaching requirements (10% of the calculated applied irrigation water was additionally applied per irrigation during the growing season for leaching purposes). Before each irrigation event, the amount of irrigation time was calculated by monitoring the actual emitter discharge using the equation provided by **Ismail (2002):**

$$t = (AIW \times A) / q$$

Where:

AIW: applied irrigation water **t** : irrigation time (h),

A : wetted area (m^2) **q:** emitter discharge (Lh^{-1}).

2.2. Applied irrigation water

The amount of applied irrigation water (AIW) for both seasons of the Geranium plant based on ETo in Table 2 was calculated. Data are shown in Table 3.

Table (3). The amount of average applied irrigation water (AIW) for the two growing seasons of Geranium plant

Irrigation water stress	**AIW (m^3/fed).**	
	Four week before the first cut (during April)	Four week before the second cut (during September)
100% of ETo	300	400
70% of ETo	210	280
60% of ETo	180	240
50% of ETo	150	200
40% of ETo	120	160
30 % of ETo	90	120

Geranium plants were harvested on May representing the first cut and a second cut was taken on October, for the 1st and 2nd seasons, respectively. Harvesting was done by cutting the vegetative parts of plants 15 cm above the soil surface leaving two branches for regrowth.

Growth characteristics recorded were: plant height (cm), shoot number, fresh and dry weight of plant (g) and fresh herb yield/fed. (ton).

Essential oil productivity: Essential oil content was carried out according to the method of **ASTA (1985).** Oil yield/plant (ml) and oil kg/fed were also determined.

Determination of antioxidant activity: Antioxidant activity of geranium oil was evaluated according to the method of **(Blos, 1958)** by spectrophotometric assay uses stable 2,2-diphenyl-1-picrylhydrazil (DPPH) radical as reagent.

2.3. Statistical analysis

The obtained data were subjected to analysis of variance (ANOVA) using COSTAT statistical package and the means were compared using L.S.D. at 5% according to **Snedecor and Cochran (1982).**

3. RESULTS and DISCUSSION

Flowering stage is a key link in the transition of plants from vegetative growth to reproductive growth. So water stress levels during flowering stage has insignificant effect on vegetative characteristics *i.e.* plant height, shoots number per plant, fresh and dry herb weight of geranium.

3.1. Effect of water stress during flowering stage on plant height (cm) and shoots number/plant

Results in Table (4) showed gradual decrease in plant height, and shoots number with the increase in water stress during flowering stage in both seasons. The full irrigation level (100% of ETo) recorded the maximum values of plant height (79.33, 67.00, 83.67 and 75.13cm), and shoots number (14.67, 19.67, 16.00 and 21.33 shoot/plant) in both cuts for the first and the second seasons, respectively. While, water stress (30% of ETo) gave the minimum values of plant height (71.57, 62.17, 70.00 and 64.67 cm) and shoot number (10.00, 13.33, 9.33 and 12.33 shoot/plant) in both cuts for the first and the second seasons, respectively. These results are in agreement with **Yang *et al.* (2019)** reported that water stress during flowering stage had insignificant effect on growth characteristics of *Oryza sativa* L.

Table (4). Effect of different water stress during flowering stage on plant height (cm) and shoot number of geranium (*Pelargonium graveolens*) plants

Water stress level (ETo)	Plant height (cm)				Shoot number			
	First season (2022)		Second season (2023)		First season (2022)		Second season (2023)	
	First cut	Second cut	First cut	Second cut	First cut	Second cut	First cut	Second cut
Full irrigation (100%)	79.33	67.00	83.67	75.13	14.67	19.67	16.00	21.33
70%	77.33	66.33	80.33	73.00	14.00	18.00	15.33	19.00
60%	76.00	66.00	79.67	71.33	13.67	17.00	15.33	18.33
50%	75.86	65.03	75.00	70.00	11.67	16.33	13.54	17.00
40%	72.21	63.31	71.33	67.33	10.33	14.67	11.67	15.67
30%	71.57	62.17	70.00	64.67	10.00	13.33	9.33	12.33
L.S.D 0.05	**2.50**	**1.88**	**3.39**	**3.06**	**2.47**	**2.83**	**1.95**	**2.85**

3.2. Effect of water stress during flowering stage on fresh and dry weight/plant (g)

Results in Table (5) indicate proportional decrease in fresh and dry weight of plant with the increase in water stress levels in the last 4 weeks before harvesting in both seasons. Full irrigation (100% of ETo) recorded the maximum values of fresh weight per plant 510.33, 840.21, 540.88 and 781.75 g in both cuts for the first and the second seasons, respectively. While, severe water stress levels (30% of ETo) gave the minimum values of fresh weight per plant (366.01, 554.33, 341.58 and 580.62 g) in both cuts for the first and the second seasons, respectively. These results are in agreement with **Álvarez *et al.*, (2013)** on geranium plants, **Alishah *et al.* (2006) and José *et al.* (2016)** on basil.

These results could be explained to the effect of water stress on photosynthesis, protein degradation, stomatal closure, and a decrease in respiration and biomass production **(González-Chav *et al.*, 2018).** Also, the decrease in plant fresh weight under stress could be attributed to the reduction in water content of tissues and cells in stressed plants.

Regarding the effect of water stress levels on dry weight of plant, full irrigation 100% ETo recorded the maximum values of plant dry weight 122.48 and 195.77 g in both cuts of the first season. The same trend was observed in the second season with values (127.11 and 175.11 g) in the first and the second cuts, respectively. While, the minimum values of plant dry weight 84.18, 128.05, 78.56 and 139.93 g were obtained with severe water stress level 30% of ETo in both cuts for the first and the second seasons. The same results were consistent with results reported by **Machiani *et al.*, (2021)** on thyme (*Thymus vulgaris* L.).

Table (5). Effect of water stress during flowering stage on fresh and dry weight/plant (g) of geranium (*Pelargonium graveolens*) plants

Water stress level (ETo)	Fresh weight/plant (g)				Dry weight/plant (g)			
	First season (2022)		Second season (2023)		First season (2022)		Second season (2023)	
	First cut	Second cut	First cut	Second cut	First cut	Second cut	First cut	Second cut
Full irrigation (100%)	510.33	840.21	540.88	781.75	122.48	195.77	127.11	175.11
70%	463.60	782.68	500.35	724.02	106.63	182.36	115.08	162.18
60%	442.35	765.70	478.13	700.13	101.74	178.41	111.88	156.83
50%	420.75	739.12	453.84	686.97	98.03	175.17	108.92	154.57
40%	379.65	560.49	360.48	613.34	87.32	130.59	82.91	144.56
30%	366.01	554.33	341.58	580.62	84.18	128.05	78.56	139.93
L.S.D 0.05	**22.78**	**26.83**	**26.04**	**33.11**	**5.18**	**4.37**	**6.32**	**5.71**

3.3. Effect of water stress during flowering stage on fresh yield/fed. (Ton)

Results recorded in Table (6) showed that an increase in water stress levels resulted a significant decrease in fresh herb yield compared to full irrigation (100% of ETo). Severe water stress level (30% of ETo) produced the lowest values of fresh yield 7.32, 11.09, 6.83 and 11.61 ton/fed., in both cuts for the first and the second seasons, respectively. However, full irrigation (100% of ETo) recorded the maximum values of fresh herb yield 10.21 and 16.80 ton per feddan in both cuts of the first season. Also, in the second season, fresh herb yield values were 10.82 and 15.64 ton per feddan. While, water stress at 70%, 60% and 50% of ETo caused a slight decrease in yield compared to severe water stress levels (30% ETo). It is also noticeable the differences between water stress levels were non-significant. Similar to our results, it was found that increasing levels of water deficit reduce yield due to reduction in photosynthesis and plant biomass of *Thymus daenensis* **(Bahreininejad *et al.*, 2013).**

Table (6). Effect of water stress during flowering stage on fresh herb yield (kg) of geranium (*Pelargonium graveolens*) plants

Water stress level (ETo)	First season (2022)			Second season (2023)		
	First cut	Second cut	Total	First cut	Second cut	Total
		Fresh herb yield/fed. (ton)				
Full irrigation (100%)	10.21	16.80	**27.01**	10.82	15.64	**26.45**
70%	9.27	15.65	**24.93**	10.01	14.48	**24.49**
60%	8.85	15.31	**24.16**	9.56	14.00	**23.57**
50%	8.42	14.78	**23.20**	9.08	13.74	**22.82**
40%	7.59	11.21	**18.80**	7.21	12.27	**19.48**
30%	7.32	11.09	**18.41**	6.83	11.61	**18.44**
L.S.D 0.05	**0.45**	**0.56**		**0.51**	**0.53**	

3.4. Essential oil productivity

The synthesis of the essential oil, secondary metabolites produced in aromatic plants, it doesn't just depend on genetics, stages of development plants and environmental condition. As such, the water status of plant should affect the grow the process and thus influence the accumulation of essential oils. The rate of vegetative growth, reproduction, flowering, and yield are all negatively affected by water stress.

However, when focusing on biosynthesis of secondary metabolites, there is a positive reaction to limited water supply. The formation and accumulation of the essential oil tended to increase under dry condition.

3.4.1. Effect of water stress during flowering stage on essential oil content and yield

The obtained results in Table (7) showed that water stress level for the last 4 weeks before harvesting improved significantly essential oil content. The severe water stress (30% and 40% of ETo) gave the maximum values of essential oil content 0.31, 0.20, 0.30 and 0.20% in both cuts for the first season. Also, in the second season, essential oil content values were 0.27, 0.20, 0.26 and 0.19 in the first and the second cuts, respectively. Followed by water stress 50% of ETo (0.30 and 0.19%) in both cuts of the first season. The same trend was observed in the second season with values (0.26 and 0.19%) in the first and the second cuts, respectively. The differences between these treatments were non-significant. While the minimum values of essential oil content 0.16 and 0.11% were obtained with full irrigation 100% of ETo in both cuts of the first season. As well, in the second season 0.14 and 0.12% in both cuts. This could be attributed to increase in number of glandular hairs per leaf in relatively severe water stress **Mulugeta *et al.*, (2023).**

Results of essential oil yield showed variation between different water stress treatments. Minimum essential oil yield 0.82 and 0.92 ml per plant and 13.06 and 14.79 kg per feddan was obtained by 100% of ETo in both cuts of the first season. The same trend was observed in the second season 0.76 and 0.94 ml per plant and 12.72 and 15.01 kg per feddan in the first and the second cuts respectively. Furthermore, maximum essential oil yield 1.26 and 1.40 ml per plant and 20.20 and 22.47 kg per feddan was obtained by water stress (50% of ETo) in both cuts of the first season. Also, in the second season, 1.18 and 1.31 ml per plant and 19.82 and 21.93 kg per feddan in both cuts. These findings are in agreement with results obtained by **De Abreu and Mazzafera (2005)** on *Hypericum brasiliense* and **Simon *et al*. (1992)** on sweet basil, **Alkir and Simon (1993)** on peppermint **Kleinwächter *et al.* (2015)** on thyme, **Tashakorizadeh *et al.*, (2022)** on *Fumaria parviflora* and **Mulugeta *et al.* (2023)** on *Ocimum* species.

Table (7). Effect of water stress during flowering stage on essential oil productivity of geranium (*Pelargonium graveolens*) plants

Water stress level (ETo)	Essential oil (%)				Essential oil yield/plant (ml)				Essential oil yield/fed. (kg)			
	First season (2022)		Second season (2023)		First season (2022)		Second season (2023)		First season (2022)		Second season (2023)	
	First cut	Second cut	First cut	Second cut	First cut	Second cut	First cut	Second cut	First cut	Second cut	First cut	Second cut
100%	0.16	0.11	0.14	0.12	0.82	0.92	0.76	0.94	13.06	14.79	12.72	15.01
70%	0.19	0.13	0.16	0.14	0.88	1.02	0.80	1.01	14.09	16.28	13.45	16.22
60%	0.26	0.16	0.22	0.17	1.15	1.23	1.05	1.19	18.40	19.60	17.67	20.00
50%	0.30	0.19	0.26	0.19	1.26	1.40	1.18	1.31	20.20	22.47	19.82	21.93
40%	0.30	0.20	0.26	0.19	1.14	1.12	0.94	1.17	18.22	17.94	15.75	19.58
30%	0.31	0.20	0.27	0.20	1.13	1.11	0.92	1.16	18.15	17.74	15.49	19.51
L.S.D=0.05	**0.01**	**0.01**	**0.01**	**0.01**	**0.10**	**0.12**	**0.11**	**0.13**	**1.01**	**1.26**	**1.22**	**1.15**

3.4.2. Effect of water stress during flowering stage on essential oil components of geranium plants in the first cut of the 2022 season.

The relative percentage of geranium component identified essential oil according to their retention time are presented in Table (8). A total of 16 constituents were identified in geranium oil. The essential oil was characterized by high amounts of oxygenated components (68.51-76.08%). Citronellol (with contents of 21.04 - 29.28%), Geraniol (with contents of 10.71 - 15.56%), linalool (with contents of 8.13 - 12.83%), geranyl formate (with contents 0.90 - 2.54), citronellyl formate (with contents of 4.48 - 8.79%) and Geranyl acetate (with contents 2.36 - 4.67%) represent the main oxygenated components. Other components present in minor concentration were hydrocarbon (3.08-11.49%). α- pinene (0.34-

2.03%), β- pinene (0.12-2.11%), Ocimene (0.71-2.27%), limonene (0.21-3.29%) and β- caryophyllene (0.81-2.04%).

The results showed that geranium oil is rich in oxygenated monoterpenes, which exhibit a broad spectrum of biological activities.

Water stress during flowering stage of geranium plants induced alterations in the chemical composition of the essential oil (Table 8). The percentage of citronellol and citronellyl formate decreased gradually with increasing water stress levels. On the contrary, the percentages of both geraniol and geranyl formate increased gradually with applying less water amounts up to 50 % of ETo. Likewise, **Eiasu *et al.* (2009)** found that increasing geraniol and geranial formate contents with increasing water stress levels which accompanied by decreasing in citronellol and citronellyl formate contents. Increasing water stress accelerated the transformation of hydrocarbons (α- pinene, β- pinene, Ocimene, limonene and β- caryophyllene) to their oxygenated constituents **(Alhaithloul *et al.* 2019).**

Results recorded in (Table 8 and Fig. 1) show that reduction in water stress levels increased C/G ratio, the citronellol : geraniol ratio was within the desired limit at water stress level 50% of ETo (C/G 1.53), followed by (C/G ratio 1.81) which was found in essential oil of plants stressed at 40% of ETo compared with 100% of ETo treatment (C/G ratio 2.73).

Water stress altered geranium oil composition. Water stress level (50% of ETo) increased geraniol and lowed citroellol. Citronellol and geraniol ratio are usually an indicator to geranium oil quality. C:G ratio is the range of one to three is acceptable **(Motso *et al.* 2006).**

From the aforementioned results the producers can apply the water stress during flowering stage in geranium plants to suit their desired oil composition. The results were similar to those obtained by **Dyubeni *et al.* (2012).** Also, **Sangwan *et al.* (1994)** found that the stress-mediated changes in lemongrasses oil composition were more prominently reflected in the major oil constituent *i.e*. citral and geraniol. As a horticultural exploitation of the stress effect on essential oil production. Stressful environments are thought to increase the synthesis of secondary metabolites. **Sangwan *et al.* (1993)** found that Short-term water stress substantially affected essential oil biosynthesis and the response was different in various Cymbopogon species.

In another set of experiments, effects were studied of long term in plant, water deficit in two lemon grasses *C. nardus* var. confertiflorus and *C. pendulus*. The major oil constituents, geraniol and citral increased in both species under water stress. The activity of geraniol dehydrogenase was also modulated under water deficit. **Sangwan *et al.*, (1993, 1994).**

3.4.3. Effect of water stress during flowering stage on antioxidant activity

The antioxidant activity was expressed as amount of free radical scavenging activity (DPPH). Data presented in Table (9) and illustrated in Fig. (2) showed the effect of water stress level during flowering stage on antioxidant activity of geranium oil. The results revealed that the antioxidant activity of geranium oil increases when the plant was exposed to water stress. The maximal scavenging activity (IC_{50} = 74.07 µg/ml of essential oil) was obtained by 50% of ETo followed by 40% of ETo (IC_{50}73.76 µg/ml), while full irrigation 100% of ETo recorded lower activity (IC_{50} = 73.43 µg/ml of essential oil).

These results could be assumed that different water stress levels play a role in antioxidant activity in plants. Despite the negative effects of water deficit, some studies reported positive effects and an improving essential oil quality due to increasing the antioxidant activity components. These results were in agreement with **Sangwan *et al.*, (2001) and Pradhan *et al*. (2018).**

As indicated GC-MS results in Table (8), it could be observed that linalool, citronellol and geraniol represent the main components geranium oil that affect its antioxidant activity (**Boukhris, *et al.*, 2013, Singam, *et al.*, 2015, Sharopov, *et al*., 2017 and Obeid and Jaber, 2018)**.

Table (8). Effect of water stress during flowering stage on essential oil components of geranium (*Pelargonium graveolens*) plants during first cut of the first season

Components	class	Water stress based on ETo					
		100%	70%	60%	50%	40%	30%
α-pinene	HC	2.03	1.67	1.37	1.14	1.09	0.34
β-pinene	HC	2.11	1.21	1.19	1.05	0.98	0.12
Ocimene	HC	2.27	1.54	1.27	0.89	0.71	1.26
Limonene	HC	3.29	2.78	1.06	0.52	0.32	0.21
Linalool	OC	8.13	8.91	12.35	12.83	11.54	10.15
Rose oxide	OC	0.95	0.26	1.19	0.31	1.30	0.36
Isomenthone	OC	5.23	4.21	3.28	3.71	3.93	4.59
α-Terpineol	OC	2.22	3.63	4.34	2.22	2.78	3.82
Nerol	OC	2.00	2.02	2.73	3.29	4.54	5.37
Citronellol	OC	29.28	28.65	25.14	23.78	22.63	21.04
Citral	OC	0.90	1.56	1.78	2.36	2.19	2.44
Geraniol	OC	10.71	11.03	11.19	15.56	12.51	11.3
Geranyl formate	OC	0.90	1.73	1.89	2.54	1.98	1.27
Citronellyl formate	OC	8.79	7.19	7.02	5.37	4.62	4.48
Geranyl acetate	OC	2.36	4.67	3.80	4.11	2.53	3.69
β-Caryophyllene	HC	1.79	2.04	1.25	0.87	0.81	1.15
HC=hydrocarbon components		**11.49**	**9.24**	**6.14**	**4.47**	**3.91**	**3.08**
OC=oxygenated components.		**71.47**	**73.86**	**74.71**	**76.08**	**70.55**	**68.51**
Total		**82.96**	**83.1**	**80.85**	**80.55**	**74.46**	**71.59**
Other Components		**17.04**	**16.9**	**19.15**	**19.45**	**25.54**	**28.41**
Citronellol and geraniol ratio (C:G)		**2.73**	**2.60**	**2.25**	**1.53**	**1.81**	**1.86**

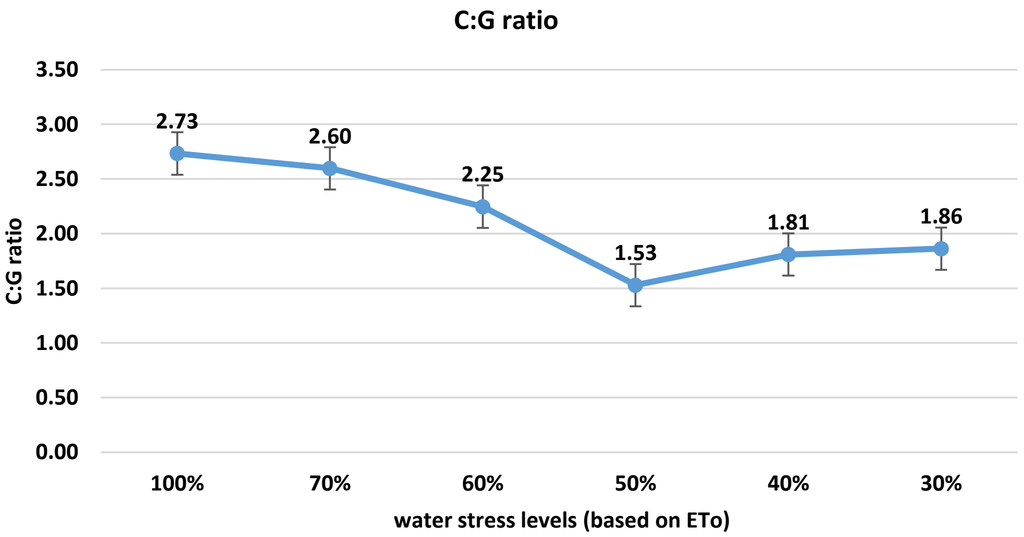

Fig. (1). Effect of water stress during flowering stage on C:G ratio

Table (9). Effect of water stress during flowering stage on antioxidant activity of geranium oil (*Pelargonium graveolens*) plants during first cut of the first season

Water stress level	Antioxidants IC_{50} (µg/ml)
Full irrigation 100% of ETo	73.43
70% of ETo	73.62
60% of ETo	73.64
50% of ETo	74.07
40% of ETo	73.76
30% of ETo	73.67
L.S.D 0.05	**0.05**

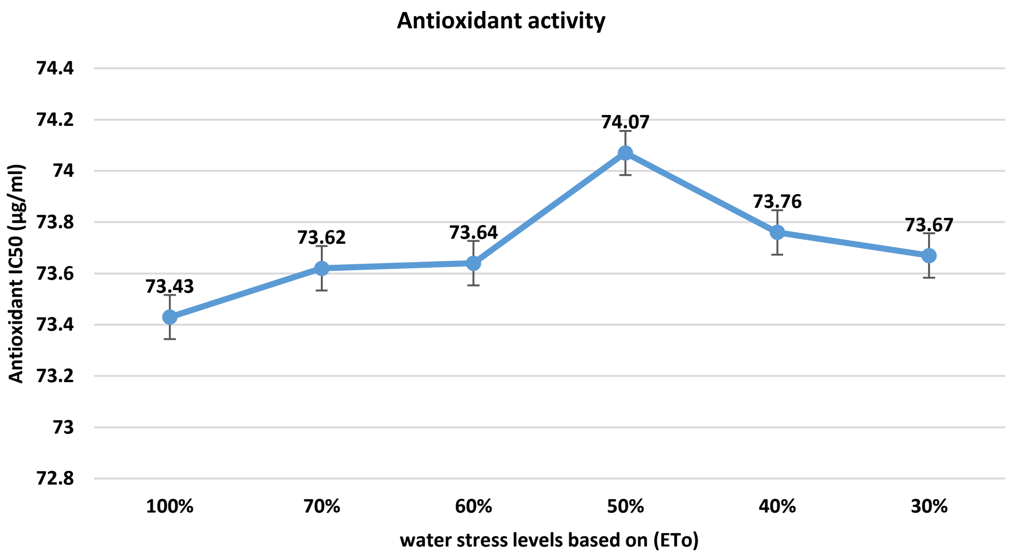

Fig. (2). Effect of water stress on antioxidant activity of *Pelargonium graveolens* essential oil using DPPH test (IC_{50} = 0.802 mg/ml)

4. Conclusions

It could be concluded that water stress in geranium when correctly timed and of appropriate duration could increase essential oil content and composition. Water stress 50% ETo during flowering stage (about four weeks before harvest) proved to be a good cultural practice for geranium oil production, and improved its quality as compared with the application of full irrigation (100% ETo).

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