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Response to Drought Stress of Three Snapdragon (*Antirrhinum majus* L.) Cultivars

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DROUGHT stress is the greatest vital abiotic factor, unfavorably affecting growth and horticultural production. The response of three Snapdragon cultivars, Crackle and Pop Exp. ('White,' 'Red,' and 'Yellow') to water deficit was studied by evaluating the morphological, physiological (leaf water relations and gas exchange assessed), photosynthetic leaf pigments, and mineral components (Mg, Ca, K, P, and N) traits. Plants were subjected to two different water deficits: well-watered at 100% field capacity (F.C.) (control), and decreased irrigation at 80% and 60% F.C. (drought stress) treatments. Cultivars varied in their response to the water deficit. Under 100% F.C., the Red cultivar had the greatest vegetative growth, but the white showed the greatest flower yield. Water deficit stress decreased plant height, number of branches and leaves, and leaf area in all cultivars. The root growth was delayed in the 'Yellow' cultivar compared to other cultivars. Under drought stress, 'White' gave the maximum spike yield; however, 'Yellow' had the lowest yield. Cultivar 'Red' had high P_n, C_i rates and a great value of plant pigments, mineral components (N, K, Mg), and water status, under favorable and water deficit stress conditions. Among the studied cultivars, 'Red' seemed more water deficit stress-tolerant than 'White,' as reflected through spike yield and vegetative growth traits.

Keywords: *Antirrhinum majus,* drought Stress, gas exchange, leaf water relation, proline, Snapdragon.

Introduction

Drought is one of the most common critical environmental factors that affect the production and growth of numerous horticultural plants and field crops worldwide (Sanjari et al., 2021 and Rodan et al., 2021). Climate change has diverse effects on the quantities of light, precipitation, temperature, and other climatic factors, negatively impacting plant performance in several regions of the world. This has led to the creation of severe soil drought environments and the spread of vast deserts (Kang et al., 2009, Conesa et al., 2018 and Ray et al., 2019). Decreased precipitation and increased temperature result in drought stress and heat in many areas, particularly semi-arid and arid regions (Li et al., 2019 and Desoky et al., 2020). Reduced water availability induces several biochemical and physiological changes in all plant tissues. As a result, plants' leaf gas exchange system becomes limited, leading to a decrease in carbon assimilation. Alterations in the photo-assimilates distribution can reduce growth and severely hinder the development of plant reproductive organs (Klamkowski and Treder, 2008).

The most long-lasting method of coping with drought conditions is thought to be introducing and cultivating drought-tolerant ornamental plant varieties. The water needs of these plant species are roughly half those of non-water deficit-tolerant plants. Among ornamental flowering plants, *Antirrhinum majus* L., usually known as Snapdragon, belongs to the family Scrophulariaceae and is native to the Mediterranean. Recently, 20,000 cultivars and 36 species of *Antirrhinum* have been identified

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(Rogers, 1992 and Carter & Grieve, 2008). *Antirrhinum majus* L. has hinged flowers that close and open similar to a dragon's mouth when pinched at the sides by the thumb. Bulir (2009) reported that these cultivars are categorized based on their flowering and growth response to temperatures and day length. Blamey and Grey-Wilson (2004) noted that Snapdragons are commonly cultivated as bedding annual plants. Dwarf Snapdragon cultivars are excellent plants for rock gardens, raised beds, border edges, and landscaping. Hamza et al. (2013) suggest that high varieties are used as the main feature in a mixed bed or as cut flowers, as well as for background purposes. Growing flower crops, compared to traditional crops, provide additional marketing opportunities for formers at both large and small scales, making them suitable for today's more selective market. Horticultural crops are grown for use in more than 140 countries with worldwide (Carter and Grieve, 2008).

For several horticultural and crop species, cultivar- or genotypic-based differences in drought tolerance have been evident (Herralde et al., 2001). However, there still needs to be more data regarding cultivars under limited water availability.

One of the key elements influencing the plants' attractiveness. Horticultural crops like ornamental plants require extensive irrigation and are vulnerable to water deficits (Sánchez-Blanco et al., 2019). Saavoss et al. (2016) stated that irrigation water management in ornamental plants is interesting in numerous aspects, such as deficiency in water storage capacity, irrigation technique, and irrigation frequency of irrigation.

This investigation aimed was to enhance knowledge of the physiological reactions of three cultivars of Snapdragon to water deficit stress conditions. We studied the effect of three levels of water deficit stress on the morphological aspects (vegetative growth and productivity traits), physiological parameters (gas exchange and water status measurements), and biochemical factors (leaf pigments, proline, and mineral components) in Snapdragon cultivars that differ in drought tolerance.

Material and Methods

Plant materials and growth conditions

Snapdragon cultivar seeds (*Antirrhinum majus* , Via Parte, Lompoc, CA, U.S.A.) were germinated in peat moss in plastic germination trays measuring 60x 50cm under a greenhouse with stable night/day temperatures of 18°C/22°C. The germination took place at the College of Food and Agricultural Sciences (CFAS), King Saud University, located at latitude 24°44'12.66"N and longitude 46°37'13.32"E in Riyadh, Saudi Arabia. The germination process occurred during two seasons, namely 2018 and 2019 (Table 1). The Snapdragon seeds were sown in the nursery on October 4th and 2nd for the respective seasons. After three weeks, the seedlings were transplanted into plastic pots with a height diameter of 15 cm (2.9Kg). The pots were filled with a mixture of sandy and loam soil in a 1:1(v:v) ratio as shown in Table (2).

Treatments and cultivars

An investigation was conducted using three cultivars of Snapdragon: Crackle and Pop Exp. White (White spike), Red (Red spike), and Yellow (Yellow spike), along with three drought levels (100, 80, and 60%) of field capacity (F.C.) (545, 435, and 330 ml), respectively. Twenty-eight days after planting, water deficit irrigation treatments were applied to the Snapdragon plants using a manual irrigation water system.

Measurements

Data on flowering yield and vegetative growth traits were recorded at the end of each season separately; however, mineral components were estimated only in the second season.

Vegetative growth traits

The number of branches and leaves, plant height (cm), leaf area (cm^2) using the Model system (3000) (LI-COR, Inc., Germany), root length (cm), and dry weights of shoots and root parts (g) were measured. To determine the dry weight, the samples were placed in a thermo ventilated oven at 70°C for 48 hours until a constant weight was achieved. The weight was then documented directly.

Flower yield traits

Spike height (cm), number of spikes, flowering time (days), spike diameter (mm), flower stalk height (cm), and flower fresh and dry weights (g) were recorded using the same method to dry tissues.

Leaf Photosynthetic pigments

Extraction of photosynthetic pigments content in *Antirrhinum majus* L. plant Total chlorophyll content, a, b, and a/b ratio were carried out using N, N- dimethylformamide (DMF) with HCl method measured in young fully expanded fresh leaves. Chl_{total} = 19.43 $OD_{663.8}$ – 8.05 $OD_{646.8}$; Chl_a = 13.43$OD_{663.8}$– 3.47$OD_{646.8}$; Chl_b = 22.90 $OD_{663.8}$ – 5.38 $OD_{646.8}$ were established in accordance with Porra et al., (1989). Carotenoid= (1000 OD_{470}− 0.89 [Chl_a] −52.02 [Chl_b]/245 (Vicaș et al., 2010) and anthocyanin= OD_{530}− 0.25OD_{657} (Mancinelli 1994). Proline levels were determined calorimetrically in fresh Snapdragon plant samples as a method by Sadasivam and Manikam (1996).

Gas exchange

Leaf gas exchange was measured in completely expanded fourth leaves using a mobile photosynthesis system Li-COR6400 (LI-COR Inc., Lincoln, USA). The transpiration rate (E), intercellular CO_2 concentration (C_i), stomatal conductance H_2O (g_s), and the net photosynthetic rate (P_n) were determined between 10:15 and 11:15 am on a sunny day with a humidity of ~57%, ambient temperature of 29°C, and photosynthetic photon flux density (PPFD) of ~1050 μmol $m^{-2}s^{-1}$, relative to the reference CO_2 levels of the respective growth chamber.

Mineral components

Four samples per treatment/cultivar were taken from four different randomly selected plants, rinsed in distilled water, dried to a constant weight, ground, and ashed at 550°C. Ash was extracted from the samples at a consistent rate using HNO_3, following the method of Kaya and Higgs (2002). Total nitrogen in samples of 0.1 g of dry weight was determined using the Kjeldahl technique, following the method of Nelson and Sommers (1973).

The sample solution's chemical composition was measured across the board. Magnesium (Mg^{2+}) and Calcium (Ca^{2+}) were measured via atomic absorption (Mo.2380, PerkinElmer, USA). Potassium (K^+) and Sodium (Na^+) levels were estimated via a flame photometer (Model Corning400, UK) following the technique described through the A.O.A.C. (2000) process. Phosphorus (P) was examined by the vanadate-molybdate technique (Chapman and Pratt, 1961).

Leaf water relations

To estimate the water use efficiency (WUE, g/L), water potential (Ψ_L), and relative water content (RWC%), the fifth fully expanded leaf from the crowns of the Snapdragon plants was used.

WUE was measured using the daily water intake as a total (plant water consumed over the four-week period). Whole Snapdragon WUE was measured as WUE = (DW final biomass −DW initial biomass)/total water consumed.

RWC was estimated using leaf discs according to the equation of Kramer and Boyer (1995) as (LFW –LDW)/(LTW –LDW)×100, where LFW stands for "leaf fresh weight," LDW for "leaf dry weight," and LTW for "leaf turgid weight" (measured after putting discs on distilled water for four hours at 5°C).

Ψ_L was determined using a portable PSYPRO (Wescor Inc., Utah, USA) leaf water potential system, including a pressure chamber. Estimates were continuously performed at approximately 10:30 AM, the time of day when light intensity was at its highest, and thus, when the water potential and water capacity of the leaves of the Snapdragon plant were at their maximum and minimum values, respectively.

Statistical analyses

A complete randomized block design following the split plot arrangement, in three replicates and analysis of variance (ANOVA) were used to statistically analyze the collected data (Steel et al., 1997). Means were separated using the least significant difference (LSD) test in SAS V.9.3 software (SAS Institute, Cary, NC, USA, 2009). The differences between water deficit and irrigation were evaluated, and the level of significance was set at $P \leq 0.05$.

Experimental design

Snapdragon, Crackle and Pop Exp. White (White spike), Red (Red spike), and Yellow (Yellow spike) cultivars were randomly assigned to the main plots, and the three water deficit treatments (100, 80, and 60% FC levels of irrigation water) were assigned to the subplots. Five potted Snapdragon plants were used in each replication of each plot. In total, the responses of 135 plants were assessed: three cultivars of Snapdragon (White, Red, and Yellow) × three irrigation water deficit treatments (100, 80, and 60% levels) × five plants per replicate × three replicates).

Results

Results showed changes in the morphology, physiology, and biochemistry of the different parts of the plant of drought-susceptible (White, Red, and Yellow) cultivars of Snapdragon plants exposed to diverse water shortage stress. These changes are shown in the tables and figures.

Vegetative growth traits

Data showed that water deficit significantly affected leaf area, plant height, branches and leaves number, and root dry weight. It also significantly affected on shoot dry weight and root length (Table 3).

Between water deficit treatments, maximum plant heights of 17.46 cm and 17.96 cm (first and second seasons, respectively) were detected in cultivars Red, White, and Yellow, when full-grown under 100% FC condition (control). However, these were smallest at 60% FC, with values of 15.93 cm and 15.13 cm (Red), 15.93 cm and 15.65 cm (White), and 10.71 cm and 10.26 cm (Yellow).

Among cultivars, maximum plant height was determined in Red cv. on average, as it was a taller cultivar compared to the others. In this study, Red cv., grown under water deficit conditions, responded better than Yellow cv., which struggled to maintain a respectable plant height, showing somewhat lesser height decreases as drought stress increased. It was also detected that water stress reduced the number of leaves per plant in cultivars Red, White, and Yellow from 100% FC (107.30 and 104.65), (100.68 and 103.30), and (97.65 and 89.31) in the first and second seasons, respectively, to 60% FC (66.29 and 63.29), (91.69 and 89.70), and (50.30 and 50.32), respectively. Among cultivars, more average leaves number was measured in Red cv. on all drought treatments compared to other cultivars (Table 3).

Data presented that inhibition of leaf development also reduces the size and volume of new leaf tissues, resulting in a reduction in leaf area. Leaf area was decreased to (40.94 and 39.98 cm^2, 60.93 and 72.19 cm^2, and 69.82 and 73.14 cm^2) at 60% FC from (75.74 and 70.01 cm^2, 90.12 and 88.77 cm^2, and 90.73 and 86.95 cm^2) at 100% FC in the first and second seasons, in cultivars Yellow, then White, and Red, respectively (Table 3).

The higher shoot dry weight was observed in cultivars Yellow, then White, and Red under 100% FC (1.81 and 1.70 g), (1.71 and 1.65 g), and (1.69 and 1.60 g) in the first and second seasons, respectively. Lesser shoot dry weight was observed in the rest of the cultivars under 60% FC: Red (1.55 and 1.50 g), White (1.49 and 1.46 g), and Yellow (1.26 and 1.27 g) in the first and second seasons, respectively (Table 3). Between cultivars, more average shoot dry weight was determined in Yellow cv. on all drought treatments compared to other cultivars.

Among the three cultivars, overall White cv. retained heavier root dry weight after a significant decrease from 1.03 and 1.05 g at 100% FC to 0.68 and 0.49 g at 60% FC. Red cv. showed a significant reduction from 0.97 and 0.95 g at 100% FC to 0.50 and 0.30 g at 60% FC. Yellow cv. showed a significant decrease in root dry weight to 0.24 and 0.20 g at 60% FC from 0.89 and 0.72 g at 100% FC in the first and second seasons, respectively (Table 3).

Results in Table 1 show that for the three cultivars, root length generally increased initially before decreasing as the severity of the drought increased. Additionally, it was found that the root lengths of the three cultivars were significantly different from one another, with the White cv. responding better to dry conditions. White cv. achieved the longest root (38.33 cm and 49.87 cm) at 100% FC, whereas Red cv. (37.63 cm and 34.96 cm) and Yellow cv. (33.53 cm and 33.30 cm) had shorter root lengths. At 60% FC, White cv. (32.13 cm and 27.23 cm) had shorter root lengths than Red cv. (31.68 cm and 28.93 cm) and Yellow cv. (30.30 cm and 23.29 cm). The cause for the improved performance of White cv. might be that its root system could have developed certain mechanisms to cope with the water deficit. In all drought treatments, White cv. achieved the greatest average root dry weight and root length across cultivars.

Flower yield traits

In our investigation, important changes in flower yield characters were detected in the Snapdragon plants subjected to drought stress. The data showed that water shortage had a highly significant effect on spike height, flowering time, flower stick height, and spike diameter. However, it had a significant effect on spike number, fresh flower number, and weight of dry flower (Table 4).

The maximum spike height was observed in cultivars White, then Red, and Yellow under control (6.53 cm and 6.42 cm), (6.16 cm and 6.37 cm), and (5.93 cm and 5.68 cm) in the first and second seasons, respectively. However, lesser spike height was observed in the rest of the cultivars under 60% FC: White (5.63 cm and 5.83 cm), Red (5.56 cm and 5.23 cm), and Yellow (3.56 cm and 3.46 cm) in the first and second seasons, respectively (Table 4).

TABLE 1. Meteorological data at Riyadh, Saudi Arabia during the two growing seasons.

Months	1st season (2018/2019)							2nd season (2019/2020)						
	T (°C)		Rs ($MJm^{-2} d^{-1}$)	RH (%)	ETp (mm d^{-1})	U_2 m/s	P mm/M^{-1}	T (°C)		Rs ($MJm^{-2} d^{-1}$)	RH (%)	ETp (mm d^{-1})	U_2 m/s	P mm/M^{-1}
	Max.	Min.						Max.	Min.					
Oct.	31.2	18.4	18.44	34.7	3.43	9.91	0.30	34.1	26.0	19.23	28.1	3.26	7.53	1.30
Nov.	25.1	15.7	16.30	39.4	2.84	8.28	4.10	28.3	12.3	16.10	46.3	2.71	8.29	6.60
Dec.	20.9	13.1	11.42	43.3	1.52	8.73	9.20	21.5	11.5	12.57	47.7	1.79	9.20	10.90
Jan.	22.7	10.7	13.95	42.1	1.98	9.73	21.50	22.2	9.5	13.65	51.7	1.73	10.29	12.30
Feb.	23.5	12.6	15.48	39.1	2.68	11.2	13.90	26.3	7.4	16.41	36.9	2.31	10.85	11.10
Mar.	27.4	14.0	18.20	27.9	3.25	12.9	17.40	39.3	17.2	18.46	31.9	2.88	11.06	25.20
Apr.	30.3	19.9	21.10	26.3	19.21	12.2	18.30	33.5	21.7	21.45	34.0	21.25	13.22	26.40

Monthly average. T: temperature; RH: relative humidity; ETp: potential evapotranspiration; Rs: solar radiation; P: precipitation; U_2: wind speed. Data from the King Khaled International Airport Station, Riyadh, Saudi Arabia.

TABLE 2. Physical and chemical properties of the soil.

Soil type	Soluble cations and anions (mequiv./l)													
	Sand%	Silt%	Clay%	pH	SAR	EC (ds/m^{-1})	K+	Mg++	Ca++	Na+	HCO_3^{1-}	P(av.P)	Cl^{1-}	SO_4^{2-}	$CaCo_3$
Sand	87.5	11.4	1.1	8.23	1.41	0.96	0.05	0.28	1.01	1.12	0.27	6.79	1.23	1.06	21.42
Loamy sandy	80.9	10.4	8.7	7.9	2.85	1.56	55	2.66	7.33	5.67	2.83	8.7	9.98	3.55	2.94

TABLE 3. The relative reduction in vegetative growth traits of Snapdragon cultivars with the development of water deficit stress.

Cultivars	Irrigation % of F.C.	Plant height		Branches no.		Leaves no.		Leaf area (cm^2)		Shoot dry weight (g)		Root dry weight (g)		Root length (cm)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
White	100	16.93^{ab}	16.03^{bc}	7.68^{cd}	6.83^{bcd}	103.30^{ab}	100.68^{a}	90.12^{ab}	88.77^{a}	1.71^{ab}	1.65^{ab}	1.03^{a}	1.05^{a}	38.33^{a}	49.87^{a}
	80	16.13^{abc}	15.56^{c}	5.65^{f}	5.76^{cd}	79.70^{c}	96.33^{ab}	73.06^{cd}	86.58^{a}	1.59^{abc}	1.61^{ab}	0.71^{abc}	0.80^{abc}	35.43^{ab}	32.95^{bc}
	60	15.93^{abc}	15.13^{c}	4.30^{g}	3.83^{e}	66.29^{d}	63.29^{c}	60.93^{d}	72.19^{b}	1.49^{abc}	1.46^{abc}	0.68^{bc}	0.49^{c-f}	32.13^{ab}	27.23^{cd}
Red	100	17.46^{a}	17.96^{a}	10.33^{a}	8.83^{a}	107.30^{a}	104.65^{a}	90.73^{a}	86.95^{a}	1.69^{ab}	1.60^{ab}	0.97^{ab}	0.95^{ab}	37.63^{a}	34.96^{b}
	80	17.02^{ab}	17.53^{ab}	8.65^{bc}	7.43^{abc}	94.33^{b}	90.33^{b}	76.81^{abc}	76.13^{b}	1.56^{abc}	1.52^{abc}	0.83^{ab}	0.61^{b-e}	33.23^{ab}	31.06^{bc}
	60	15.93^{abc}	15.65^{c}	7.32^{de}	6.43^{bcd}	91.69^{b}	89.70^{b}	69.82^{cd}	73.14^{b}	1.55^{abc}	1.50^{abc}	0.50^{cd}	0.30^{ef}	31.68^{ab}	28.93^{bcd}
Yellow	100	15.35^{bc}	15.13^{c}	9.26^{ab}	8.73^{a}	97.65^{ab}	89.31^{b}	75.74^{bcd}	70.01^{b}	1.81^{a}	1.70^{a}	0.89^{ab}	0.72^{a-d}	33.53^{ab}	33.30^{bc}
	80	14.93^{c}	14.43^{c}	7.35^{de}	7.83^{ab}	54.63^{e}	52.29^{d}	45.68^{e}	53.29^{c}	1.36^{bc}	1.40^{bc}	0.42^{cd}	0.38^{def}	30.53^{b}	26.91^{cd}
	60	10.71^{d}	10.26^{d}	6.31^{ef}	5.73^{d}	50.30^{e}	50.32^{d}	40.94^{e}	39.98^{d}	1.26^{c}	1.27^{c}	0.24^{d}	0.20^{f}	30.30^{b}	23.29^{d}

*Values in each column followed by different superscript letter(s) are significantly different at $P \leq 0.05$.

TABLE 4. The relative reduction in flower yield traits of Snapdragon cultivars with the progression of water deficit stress.

Cultivars	Irrigation% of F.C.	Spike height (cm)		Spike no.		Flowering time (days)		Spike dimeter (mm)		Flower stick height (cm)		Flower dry weight (g)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
White	100	6.53^{a}	6.42^{a}	6.73^{a}	6.43^{a}	119.30^{ab}	123.33^{a}	3.54^{c}	3.63^{c}	4.43^{a}	4.36^{a}	0.49^{a}	0.44^{a}
	80	5.76^{ab}	6.13^{ab}	5.73^{abc}	6.13^{ab}	117.35^{bc}	116.69^{bc}	3.33^{cd}	3.53^{c}	4.13^{abc}	4.10^{b}	0.35^{ab}	0.34^{bc}
	60	5.63^{ab}	5.83^{b}	5.46^{abc}	5.16^{abc}	112.62^{de}	114.30^{d}	3.17^{de}	3.21^{de}	3.63^{cd}	3.92^{c}	0.29^{bc}	0.23^{bc}
Red	100	6.16^{ab}	6.37^{a}	6.44^{ab}	5.73^{abc}	115.64^{c}	117.65^{b}	4.16^{a}	4.23^{a}	4.23^{ab}	4.25^{ab}	0.28^{bc}	0.26^{bc}
	80	5.73^{ab}	5.63^{bc}	5.13^{abc}	5.36^{abc}	113.69^{d}	115.34^{cd}	3.86^{b}	4.06^{b}	3.83^{bcd}	4.13^{b}	0.25^{bc}	0.22^{bc}
	60	5.56^{ab}	5.23^{c}	4.76^{bc}	4.47^{c}	110.70^{e}	109.62^{e}	3.53^{c}	3.35^{d}	3.79^{bcd}	3.63^{d}	0.22^{bc}	0.19^{bc}
Yellow	100	5.93^{ab}	5.68^{bc}	5.53^{abc}	5.84^{abc}	120.30^{a}	124.36^{a}	3.46^{c}	3.25^{de}	4.06^{abc}	4.12^{b}	0.38^{ab}	0.36^{ab}
	80	5.46^{b}	5.31^{c}	4.83^{bc}	4.73^{bc}	117.66^{bc}	117.31^{bc}	3.04^{e}	3.13^{e}	3.63^{cd}	3.96^{c}	0.26^{bc}	0.18^{bc}
	60	3.56^{c}	3.46^{d}	4.06^{c}	4.45^{c}	108.29^{e}	103.30^{f}	3.03^{e}	2.95^{f}	3.43^{d}	3.35^{e}	0.17^{c}	0.16^{c}

*Values in each column followed by different superscript letter(s) are significantly different at $P \leq 0.05$.

Concerning water stress treatments, the higher spike number was observed in cultivars White, then Red, and Yellow under 100% FC (6.73 cm and 6.43 cm), (6.44 cm and 5.73 cm), and (5.53 cm and 5.84 cm) in the first and second seasons, respectively. However, lower spike number was observed in the rest of the cultivars under 60% FC: White cv. (5.46 cm and 5.16 cm), Red cv. (4.76 cm and 4.47 cm), and Yellow cv. (4.06 cm and 4.45 cm) in the first and second seasons, respectively (Table 4). Among cultivars, more average spike height and spike number were observed in cultivar White on all water deficit treatments compared to other cultivars.

It was also observed that water deficit reduced flowering time (days) in cultivars Yellow, White, and Red from 100% FC (120.30 and 124.36 days), (119.30 and 123.33 days), and (115.64 and 117.65 days) in the first and second seasons, respectively, to 60% FC (108.29 and 103.30 days), (112.62 and 114.30 days), and (110.70 and 109.62 days), respectively (Table 4).

Data presented that drought reduced spike diameter, which decreased to (3.53 and 3.35 mm, 3.17 and 3.21 mm, and 3.03 and 2.95 mm) at 60% FC from (4.16 and 4.23 mm, 3.54 and 3.63 mm, and 3.46 and 3.25 mm) at 100% FC in the first and second seasons, in cultivars Red, then White, and Yellow, respectively (Table 4).

Results in Table 2 show that the overall trend of flower stick height for three of the cultivars was increasing in the beginning, then deteriorating as the drought level increased. It was also observed that flower stick height among three cultivars was close and better response was attained through the White cv. under water deficit conditions. White cv. achieved the longest flower stick (4.43 cm and 4.36 cm), whereas for Red cv. (4.23 cm and 4.25 cm), and Yellow cv. (4.06 cm and 4.12 cm) in the first and second seasons, respectively, at 100% FC. These cultivars had shorter flower stick in White cv. (3.63 cm and 3.92 cm), than Red cv. (3.79 cm and 3.63 cm), and Yellow cv. (3.43 cm and 3.35 cm), respectively, at 60% FC.

Between the three cultivars, overall White cv. retained higher flower dry weight after an obvious decrease from 0.49 g and 0.44 g at 100% FC to 0.29 g and 0.23 g at 60% FC. Red cv. showed a significant reduction from 0.28 g and 0.26 g at 100% FC to 0.22 g and 0.19 g at 60% FC. Yellow cv. showed a significant decrease in flower dry weight to 0.17 g and 0.16 g at 60% FC from 0.38 g and 0.36 g at 100% FC in the first and second seasons, respectively (Table 4). Amongst cultivars, higher average flower stick height and flower dry weight were measured in White cv. on all drought treatments compared to other cultivars.

Normal growth inhibition was more pronounced in the plant portions above the soil surface (vegetative and flowering growth) than in the root systems in response to decreasing water availability.

Leaf Photosynthetic pigments

Water stress reduced chlorophyll levels in three Snapdragon cultivars. Water deficit stress imposed on the three cultivars significantly reduced chlorophyll a, b, total, and a/b ratio content (Figure 1A). Water deficit stress imposed on the three cultivars also significantly reduced total carotenoids and anthocyanin content (Figure 1B). The decrease was less pronounced in Red cv. than in White and Yellow cultivars. Red cv. was able to better tolerate the drought conditions by maintaining a higher level of chlorophylls than White and Yellow cultivars. Additionally, the ‘Red’ cv. had the highest levels of chlorophyll a, b, total, a/b ratio, total carotenoids, and anthocyanin content under 100% FC condition. However, the ‘White’ cv. had the lowest levels of chlorophyll a, b, total, a/b ratio, total carotenoids, and anthocyanin content under 100% FC condition. All three cultivars showed a decrease in chlorophyll content due to the stress caused by water shortage. However, the ‘White’ cv. displayed the lowest levels of chlorophyll a, b, total, a/b ratio, total carotenoids, and anthocyanin content under 60% FC. The leaf pigment content is reduced in response to stress conditions.

Gas exchange

Results in Figure 2 show that irrigation deficit stress conditions caused a significant decrease in transpiration (E), intercellular CO_2 concentration (C_i), stomatal conductance (g_s), and net photosynthetic rate (P_n) of the three Snapdragon cultivars. P_n, E, C_i, and g_s were all reduced in all three cultivars when they were imposed to water deficit (Figure 2A, B, C, and D). For instance, one of the first reactions of stress in Snapdragon plants is stomatal closure, which restricts the amount of gas exchange between the interior of the leaf and the atmosphere. Cultivar 'White' had the highest E, g_s, and C_i under 100% FC (control). However, 'Yellow' cv. had the lowest E, g_s, and C_i under 100% FC condition. Water deficit stress caused a reduction in all three cultivars. While 'Yellow' showed the lowest C_i under 60% FC condition. C_i decreased in response to stress. Cultivars significantly varied in net photosynthetic activities; however, these variances could only be expressed under the control conditions.

Mineral components

The proline content was significantly increased under water deficit stress in three of the cultivars (Figure 3A). However, the increase in the proline in 'White' cv. was found to be more significant than in 'Yellow and Red' cultivars. Cultivar 'White' had the highest content of proline under 100% FC (control) condition. However, cultivar 'Red' had the minimum content of proline under 100% FC. Increased proline content is a sign of water deficit stress in all three cultivars. However, cultivar 'White' had the maximum content of proline than 'Yellow and Red' cultivars under 60% FC condition.

The mineral components (N, Ca, P, Mg, and K) were significantly reduced under water deficit stress in three cultivars (Figure 3B, C, D, E, and F). However, the decrease in nutrient uptake in 'White' cv. was found to be more significant than in 'Yellow and Red' cultivars. Cultivar 'White' had the highest mineral components (N, P, and Ca) under 100% FC (control) condition. Conversely, 'Yellow' cv. had the lowest nutrient uptake (N, P, and Ca) under 60% FC. Figure 3D and F show that the mineral components (K and Mg) were significantly reduced under water stress in three cultivars. Along with access to water and reduced FC, K and Mg element absorptions in this investigation demonstrated a decreasing trend. However, the reduction in nutrient uptake (K and Mg) in cultivar 'White' cv. was found to be more significant than 'Yellow and Red'. Cultivar 'Red' had the highest mineral components (K and Mg) under 100% FC. In contrast, 'White' cv. showed the lowest mineral components (K and Mg) under 60% FC condition.

Leaf water relations

The physiological status of the Snapdragon plants was evaluated by determining relative water content (RWC), water use efficiency (WUE), and leaf water potential (Ψ_L) in the leaves (Figure 4A, B, and C).

A significant reduction in relative water content (RWC) was detected with an increase in the intensity of water deficit stress in three cultivars. In the 100% FC plants of three cultivars, there was a steady reduction in RWC in response to the degree of tolerance of the cultivar to irrigation water. However, the reduction in RWC in Red cv. was found to be more significant than in Yellow and White cultivars. Cultivar Red had the highest RWC under 100% FC of water stress, whereas cultivar 'White' showed the lowest RWC under 60% FC water stress condition (Figure 4A).

According to the investigation, water use efficiency (WUE) varied significantly depending on the water availability and the cultivar that was studied (Figure 4B). While cultivar 'White' showed the lowest WUE under 60% FC drought stress conditions, cultivar 'Red' showed higher WUE of the stressed plants compared to the other irrigated plants under 100% FC. This information suggests that the 'Red' cultivar has a greater capacity for irrigation water conservation than the other cultivars.

The three cultivars investigated presented different capacities in preserving leaf water potential (Ψ_L) under water deficit. The general trend of leaf ΨL was a decrease in the three cultivars, but at different rates, according to the tolerance of each cultivar to drought stress conditions. Cultivar 'Yellow' under 100% FC was able to maintain a higher potential (-0.603 MPa) in comparison to the other cultivars. However, cultivar 'White' presented the lowest leaf ΨL (-1.073 MPa) under 60% FC water deficit condition. This was especially visible at the end of the investigation (Figure 4C).

Discussion

Vegetative growth traits

The data described here provide additional evidence for the effects of water deficit-intolerant drought stress in three Snapdragon cultivars. Furthermore, the smallest biomass production in the lowest water deficit of 60% FC might occur because of a decrease in water uptake by the plant and accordingly a decreasing trend in the absorption of elements such as nitrogen, calcium, and total phosphorus (Figure 3), and increased drought of branches and leaves numbers, and leaf area (Table 3), in addition to as a result decreased shoot dry weight.

Water deficiency is a major serious threat to crops and horticulture worldwide. Climate change reduces precipitation and increases temperatures, and as a result increases the incidence of drought, especially in semi-arid and arid areas (Desoky et al., 2020), resulting in water deficiencies and severely weakening production and plant growth (Dai, 2013). In this context, the current research was conducted to study the tolerance of three cultivars of Snapdragon under drought stress (water deficit) conditions on morpho-physiological traits. The data implied that the water deficit significantly decreased the growth performance, for both vegetative growth (plant height, branches and leaves numbers, leaf area, and shoot and root dry weights) and flower yield (spike height, spike number, flowering time, spike diameter, flower stick height, and flower dry weight). Our results were in line with those of Bettaieb et al. (2009) who showed that plants had shorter heights and smaller leaves under drought stress in *Salvia officinalis*. Furthermore, according to previous research, drought stress decreases plant height and the number of leaves in *Dianthus* plants (Álvarez et al., 2009), and *Phillyrea angustifolia* plants (Álvarez et al., 2019). Klamkowski and Treder (2008) found that the leaf area and root length of the stressed plants were significantly decreased as compared to that of the control ones. Similar results have been previously reported for a reduction in the fresh and dry mass of root in *Tagetes erecta* (Srinivasan et al., 2018), and a reduction in the bulb mass of *Lilium davidii* (Li et al., 2020). Zhao et al. (2006) mention that the common adverse effects of water deficit on plants are the decrease in dry and fresh biomass production. A reduction in cell growth and accordingly overall plant growth is the first response to drought stress conditions (Rodriguez, 2006). Consequently, in water deficit conditions at 60% FC, the above-ground parts are affected more than the roots; in this context, the growth of the above-ground part of the plant is delayed before the roots, leading to an increased root-to-shoot ratio (Riazi et al., 2013 and Chiatante et al., 2006). A significant relationship between different plant cultivars and water deficit stress has been studied by several researchers (Dhanda et al., 2004 and Asghari et al., 2009). Plants have high success in decreasing the effects of water deficit in vegetative growth with the action of tolerance mechanisms (Oguz et al., 2022). The reduction in stem tissue size, the number of cells, which can be produced by a decrease in turgor pressure, the disruption of metabolic processes like cell differentiation and division, and photosynthesis in plants could all be responsible for this decrease in response to water deficit conditions (Ullah et al., 2018, Raja et al., 2020 and Omidian et al., 2021).

Flower yield traits

In the current research, water deficit significantly decreased the number of Snapdragon flowers compared to 100% FC (control) plants. Our findings are consistent with previous research that has shown that water stress reduces the flower length, bud width, and number of flowers in *Rose* (Farahi et al., 2012) and *Antirrhinum* plants (El-Nashar, 2017). In contrast, complete irrigation of 100% FC decreases the flower number per stem length in *Forsythia* (Davies et al., 2016) compared to those plants receiving about 50% water stress. Davies et al. (2016) showed that the variations in tissue type, age at which the flowers are initiated, species sensitivity, and the timing of application of the water stress relative to flower initiation are all factors that contribute to this effect. Plants are more sensitive to water deficit during certain critical phases like flowering (Oguz et al., 2022). Teixido et al. (2019) revealed that flowers, such as a final yield of flowers, require large amounts of water to maintain turgor and prevent wilting. Sánchez-Blanco et al. (2009) noted that it is noteworthy that under conditions of water shortage stress, the flowering rate reduces to conserve carbohydrates for crucial plant functions. Predominant drought decreases plant development and growth, leading to hampered flower production and accordingly fewer number and smaller size flowers. Decreases in flower composition occur due to a reduction in the activities and assimilate partitioning of different component (sucrose, starch, and…) synthesis enzymes.

several studies have reported that deficit irrigation is effective in modifying the flowering process (Bernal et al., 2011), increasing the shoot-to-root ratio (Álvarez et al., 2019), reducing plant height and shoot number, improving plant compactness (Álvarez et al., 2009), and limiting the rapid expansion of ornamental nursery stock (Davies et al., 2016). Cicevan et al. (2016) noted that water deficit stress triggers a decrease in fresh mass, stem length, carotenoid pigment, water content, and increased proline concentration in *Tagetes*. Drought stress conditions have been shown to decrease bulb weight, plant height, and chlorophyll content in *Lilium davidii* (Li et al., 2020). Inadequate irrigation enhanced minor metabolites and maintained ornamental characteristics in *Echinacea purpurea* (Darvizheh et al., 2019) and *Tagetes* varieties (Yasheshwar et al., 2017). Insufficient water availability in the root area affects the anatomical and physiological differences in *Lantana* and *Ligustrum* (Toscano et al., 2019), *Passiflora* (Souza et al., 2018). Additionally, Zhang et al. (2011) mentioned that growth parameters and photosynthetic processes of lily plants are affected by deficit irrigation.

Leaf photosynthetic pigments

One sign of a plant's resistance to drought is the amount of leaf photosynthetic pigments; when plants' water content declines, the quantity of this pigment decreases (Soureshjani et al., 2019 and Pour-Aboughadareh et al., 2020). We found that water deficit stress obviously reduced chlorophyll levels. This decrease in chlorophyll content (a, b, total a+b, total carotenoid, and anthocyanin) has also been observed in different sunflower cultivars (Manivannan et al., 2007) and tomato plants (Raja et al., 2020). Damage to leaf photosynthetic pigment an underwater deficit stress is the main reason for the inactivation of photosynthesis. Moreover, the reduction in photosynthetic pigments caused by water stress has been linked to several factors, including excessive swelling, damage to chloroplast membranes, the formation of lipid droplets, and deformation of the lamellae vesiculation (Kaiser et al., 1981). Low levels of plant pigments can directly restrict the potential for photosynthetic growth and hence the initial output. According to Abid et al., (2018), the decrease in stomatal conductance, which reduces CO_2 availability to chloroplast and subsequently limits photosynthetic rate, may be the cause of decreased plant pigments during water shortage conditions. Additionally, the increase in the chlorophyllase activity enzyme (Kaewsuksaeng, 2011) and chloroplast loss (Raja et al., 2020) can decrease the plant pigments. Our results are in accordance with those of the preceding reports by Zhong et al. (2020), Omidian et al., (2022), and who verified that tall fescue and Lilium had significantly more chlorophyll after receiving the water stress treatment. In another study, Water deficiency stress induced a decrease of total chlorophyll and carotenoid content significantly in strawberry plants (Zahedi et al. 2023).

Gas exchange

The gas exchange relationship is most affected by water deficit stress. Water deficit stress caused a significant reduction in the gas exchange (intercellular CO_2 concentration, stomatal conductance to H_2O and transpiration rate) of the three Snapdragon cultivars (Fig. 2). The three Snapdragon cultivars exhibited a consistent behavior with regard to the aforementioned gas exchange properties. Water availability is a limiting factor for a wide variety of physiological processes involved in plant development. One of the main responses of plants to water scarcity is stomatal conductance closure, which restricts gas exchange between the atmosphere and the inner of the leaf. Hetherington and Woodward (2003) noted that this is the main way that plants regulate carbon acquisition and water relationships. According to Chaves et al., (2003), stomatal closure protects the plant from excessive water loss, but it also reduces the amount of CO_2 that can diffuse into the photosynthetic process.

Flexas and Medrano (2002) reported that the photosynthetic apparatus is the main site of stress conditions in plants, and it is very sensitive to drought stress. The photosynthetic activity is diminished because of stomatal conductance closure and impaired gas exchange. In the current research, E, C_i, P_n, and g_s were significantly reduced in the leaves of Snapdragon under water deficit, and P_n decreased substantially in 60% F.C., indicating that the decrease in P_n in the initial stage could be attributed to stomatal conductance closure and the restriction of CO_2 absorption. Small stomatal conductance leads to greater stomatal control and stomatal resistance, and it is a rapid response to water deficit stress (Drake et al., 2013 and Zhang et al., 2022).

The results of water deficiency on E were similar to those on g_s (Fig. 2B and D). De Souza et al. (2005) reported that improved water supply caused significantly higher g_s, P_n, and *E,* which agrees with our results (Fig. 2). The cultivars studied showed changes in C_i, however in these cases, the genetic variances were only statistically significant under water deficiency stress, with 'White' cv. observed the highest values of C_i in 60% F.C. Cornic and Massacci (1996) demonstrated that a decrease in P_n under water deficiency stress can also be attributed to a decrease in g_s or/and to non-stomatal limitations. The increased C_i in the water-stressed "White" cv. reflects the predominance of non-stomatal photosynthetic limitations. Under various circumstances, both non-stomatal and stomatal limitations can reduce crop yield. Basu et al. (2004) and Mafakheri et al. (2010) stated that photosynthesis can be limited by stomatal factors under water deficiency stress.

In several studies, it has been shown that photosynthetic rate (P_n) decreases when stomatal conductance (g_s) decreases (Nilsen and Orcutt, 1996). However, according to Chaves and Oliviera (2004), g_s only affect P_n under severe water deficiency stress conditions. Both stomatal (stomatal conductance closure) and non-stomatal (deficiencies of metabolic processes) factors can be blamed for the decrease in photosynthesis in plants under water stress. Under 100% field capacity (FC), the yield of cultivars followed a similar P_n trend, with the 'Red' cv. exhibiting the highest P_n.

Mineral components

Proline is a versatile molecule that helps to reduce the negative effects of water deficit stress by acting as an osmolyte and a radical scavenger (Szepesi and Szollosi, 2018). Under drought stress, leaf water potential can be maintained by osmotic adjustment in response to the accumulation of proline and other solutes in the cytoplasm, which increases water absorption from the soil. Plants store a variety of inorganic and organic solutes in the cytosol at lower osmotic potentials in order to maintain cell turgor (Rhodes and Samaras, 1994). The accumulation of these solutes under drought stress is a process called osmotic adjustment, which strongly depends on the severity of plant water deficit stress. Proline content increases in response to osmotic stress because it is a major osmolyte that provides cellular osmotic adjustment (Zhang et al., 2017). Proline can react directly with singlet oxygen or free radicals to quench those (Siripornadulsil et al., 2002). These reactions reduce the damage caused by reactive oxygen species. Kavi Kishor et al., (2005) and Ashraf & Foolad, (2007) stated that proline plays an active role in maintaining subcellular structures, membrane integrity, cellular functions, and protein stabilization by scavenging reactive oxygen species under stress conditions. Proline is one of the main solutes that contribute to osmotic adjustment in water-stressed plants (El-Bassiouny and Sadak, 2015). Riazi et al., (2013) found that *marigold* exhibits low concentrations of these compatible solutes, and proline accumulation and mobilization were found to increase tolerance to water stress. Among these solutes, proline is the most widely studied due to its significant importance in water deficit stress tolerance. Kumar et al., (2017) mentioned that proline accumulation is a plant's initial response to water deficit stress to reduce cell damage. Progressive water deficit stress induced a significant accumulation of proline in drought-stressed plants (Verbruggen and Hermans, 2008). The proline content increased in *Betula* plants as the water deficit stress advanced (Gu et al., 2007).

Water deficit conditions typically reduce the overall soil mineral availability, root mineral translocation, and ultimately reduce the ion content in different plant tissues (Kheradmand et al., 2014). Water deficiency stress reduces plant Ca, Mg, and K absorption (Hu and Schmidhalter, 2005). This decrease in K was caused by reduced root membrane transporters, decreased E, and decreased K mobility (Hu et al., 2013). Qi et al., (2019) mentioned that a decrease in K quantity was also found in water deficit-stressed plants of Malus hupehensis. Water deprivation stress blocks K^+ transporters, and a protein kinase network, which in turn cooperates with Ca sensors such as calcineurin (B), stimulates internal K (+) channels (Li et al., 2009). Cuéllar et al., (2010) found that this K (+) channel was activated in leaves but inhibited in roots. According to García-Caparrós et al. (2019), leaf N^+ concentration did not change in water deficiency stress in *Salvia sclarea*, *Salvia lavandulifolia*, and *Mentha piperita*, while, in Thymus mastichina and *Lavandula latifolia* plants, N content decreased, but leaf P and Mg concentration decreased in all types except for *S. sclarea* whose level remained the same. Da Silva et al. (2011) noted that this decrease in N^+ was reflected as the main responsible reason for leaf senescence and photosynthesis reduction. Mainly, the reduction of K^+ quantity occurs in leaves, which causes water shortage guard cell turgidity and disturbs stomata movement, which results in declined photosynthesis and, ultimately, plant biomass production (Sarani et al., 2014). Samarah et al. (2004) found that conditions of low water availability caused the soybean plant to accumulate more N, Mg, Mn, P, K, Ca, and Zn.

Drought (water deficit) stress has many harmful effects on plant growth and yield production of various crops. It can decrease leaf absorption of photosynthetic energetic radiation and reduce the efficiency of radiation use (Earl and Davis, 2003). According to Merwad et al., (2018), it significantly reduces membrane stability index, photosynthetic rate, and leaf photosynthetic pigments. Additionally, it leads to changes in gas exchange characteristics, accumulation of toxic ions, and thereby inhibits the growth, development, and production of various plants (Kusvuran et al., 2016; Anjum et al., 2011).

Leaf water relations

The data described here provide further evidence for the effects of water shortage-intolerant drought stress in three Snapdragon cultivars. Water use efficiency (WUE), relative water content (RWC), leaf water potential (Ψ_L), canopy temperature, leaf temperature, rate of transpiration, and stomatal resistance are important parameters that affect plant water relations. RWC is used as the most insensitive metric for dehydration resistance, assessing the metabolic activity in tissues and used to determine plant water status. RWC is connected to water loss through transpiration as well as water absorbed by the roots. According to Nayyar and Gupta (2006), when leaves are subjected to water shortage, leaves show significant declines in Ψ_L and RWC. This reduction in WUE and RWC has been observed in a wide variety of plants. Siddique et al. (2001) showed that when plants are exposed to water stress, their Ψ_L, E, and RWC are significantly reduced, and their leaf temperature is subsequently increased.

Our studies showed that the RWC of Snapdragon leaves decreased under water deficit. Begum et al. (2019) and Kosar et al. (2021) advised that it is well-known that a lack of water leads to stress conditions that significantly reduce plant growth and limit a plant's ability to get water. Reduced RWC of leaves causes some changes in physiological and metabolic processes, which affects plant growth (Desoky et al., 2021 and Raja et al., 2020). Blum and Tuberosa (2018) suggest that RWC, as a physiological reaction, reveals the plant's ability to maintain a relatively high water status in the face of drought. Leaf water status is key when it comes to a plant's ability to tolerate a water shortage. According to Lilley and Ludlow (1996) and Blum and Tuberosa (2018), plants with higher RWC have a greater capacity for maximal recovery and are more resilient to environmental challenges, particularly water stress. Water deficiency stress induced a significant decrease in relative water content in plants (Zahedi et al., 2023).

In this regard, although components of plant water relations (WUE, Ψ_L, and RWC) are affected by diminished availability of irrigation water, g_s closing and an opening are more strongly affected. Furthermore, alteration in leaf temperature might be an important factor in controlling leaf water status under water deficiency stress conditions. According to Anjum et al., (2011), drought-tolerant cultivars maintain WUE and RWC by reducing water loss. However, WUE was significantly reduced in situations where plant growth was prevented to a higher extent.

Conclusion

The investigation presented revealed considerable physiological, biochemical, and morphological variations among the three Snapdragon cultivars studied. The cultivar "Red" was found to be the most tolerant of dry conditions. It was better at reducing water consumption when there was a water shortage. Under both favorable and water deficit stress situations, this cultivar possessed high levels of P_n and a high value of plant pigments, N, K, Mg, and leaf water relation. Adaptations in physiology, morphology, and biochemistry allowed "Red" plants to maintain productivity and growth when access to water was limited. The cultivar "Yellow" plants had the lowest stress tolerance levels when there was a water shortage. This cultivar's limited usefulness for agriculture in water deficit stress-prone settings is confirmed by a drop in vegetative growth and losses in flower output in response to water deficit stress.

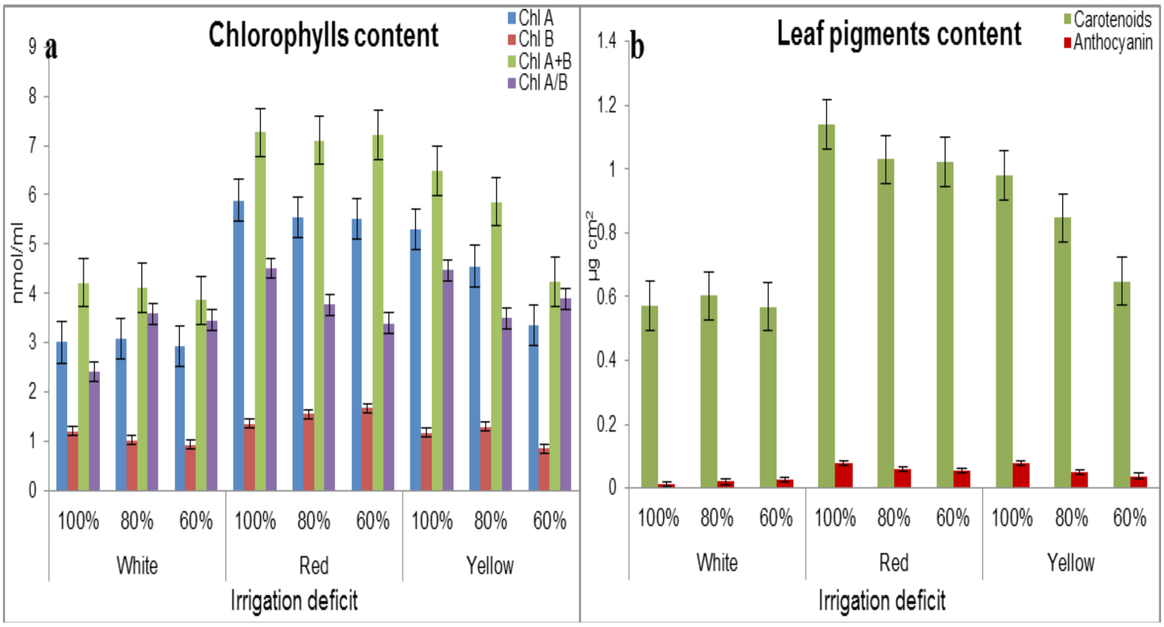

Fig. 1. The leaf pigments content a (Chlorophyll A, chlorophyll B, total chlorophyll A+B, chlorophyll A/B ratio) and b (Total carotenoid and anthocyanin); Mean ± S.E. of three Snapdragon cultivars (White, Red and Yellow) in each irrigation treatments (100, 80 and 60% F.C.).

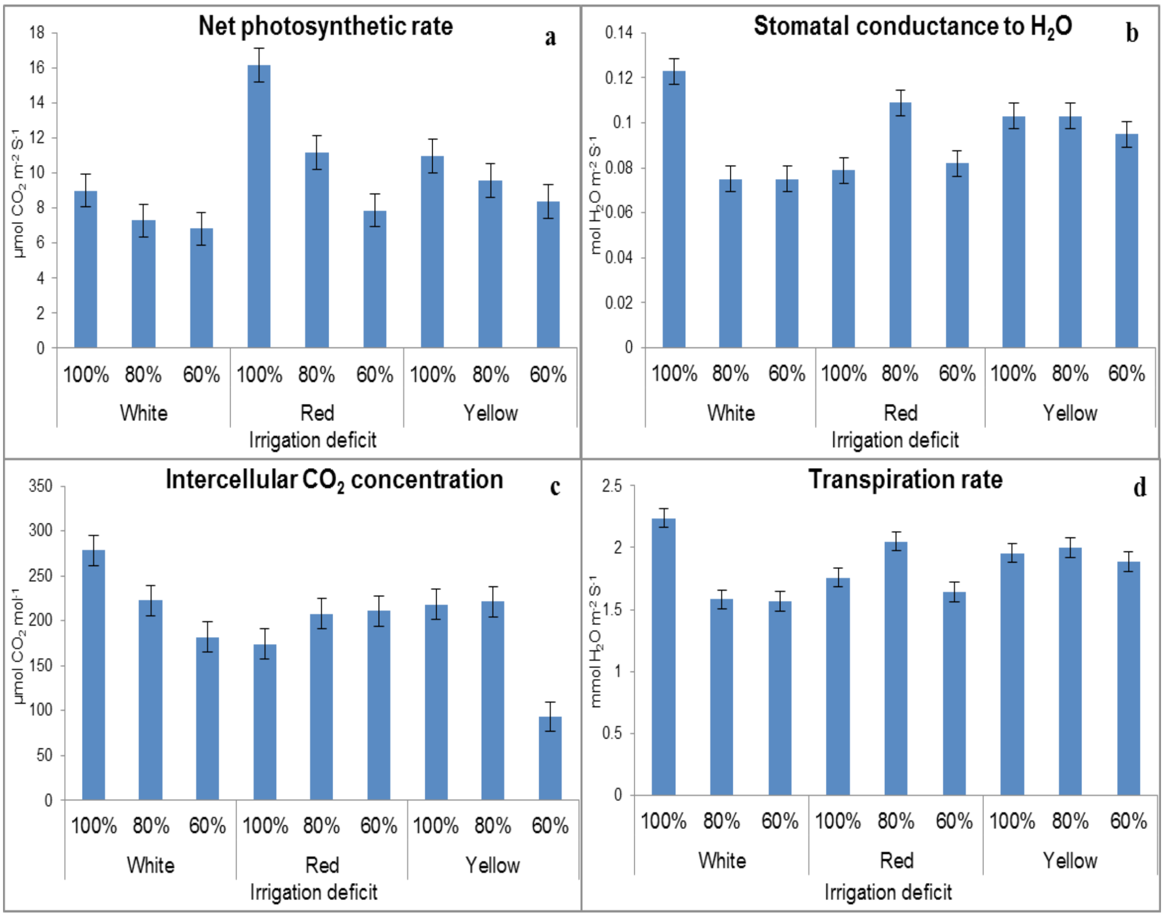

Fig. 2. The gas exchange measurements ((a) Net photosynthesis rate, (b) Stomatal conductance to H_2O, (c) Intercellular CO_2 concentration, and (d) Transpiration rate); Mean ± S.E. of three Snapdragon cultivars (White, Red and Yellow) in each irrigation treatments (100, 80 and 60% F.C.).

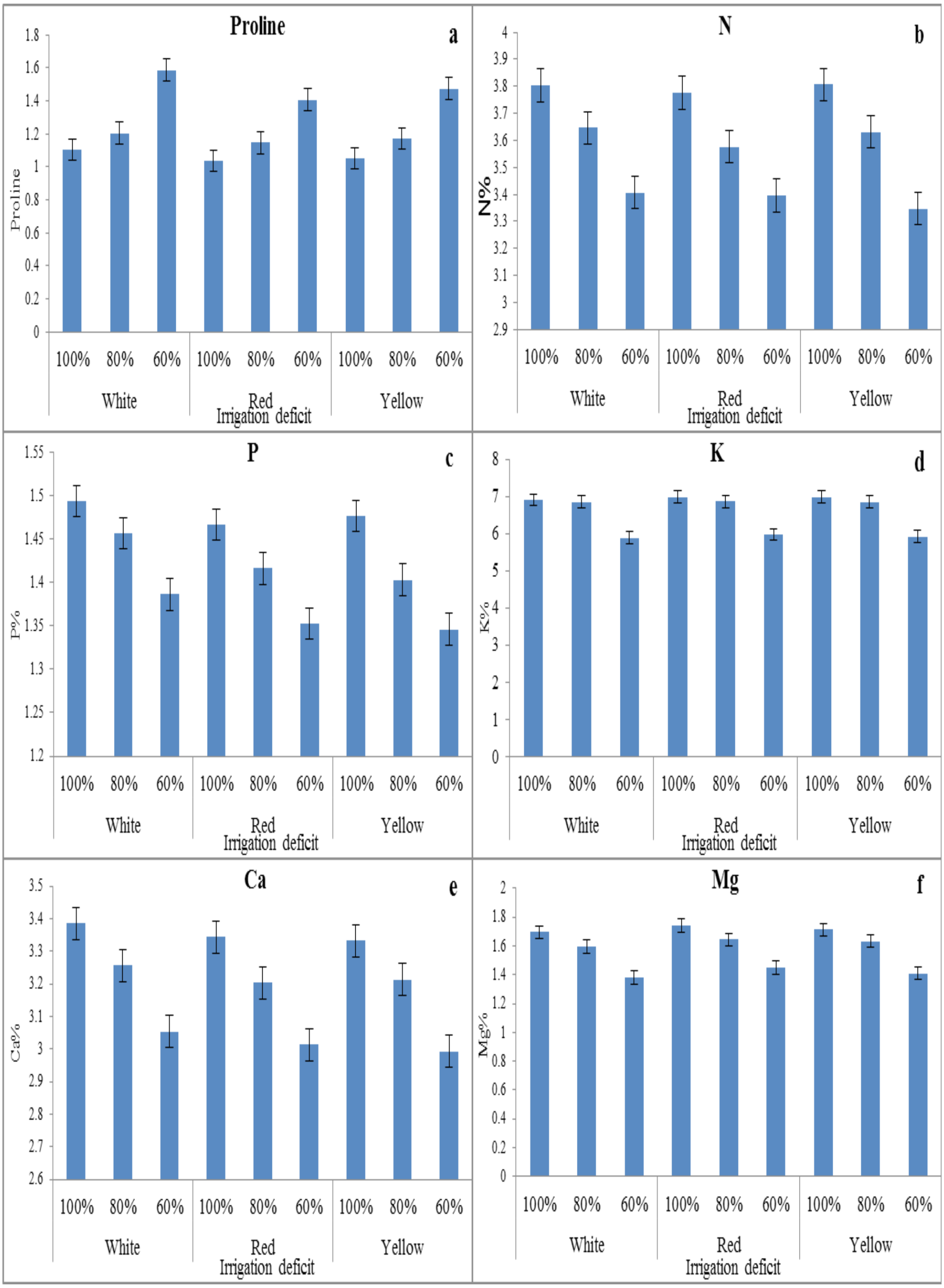

Fig. 3. Proline content (a),The mineral composition measurements ((b) Nitrogen (N), (c) Total phosphor (P), (d) Potassium (K), (e) Calcium (Ca) and (f) Magnesium (Mg)); Mean ± S.E. of three Snapdragon cultivars (White, Red and Yellow) in each irrigation treatments (100, 80 and 60% F.C.).

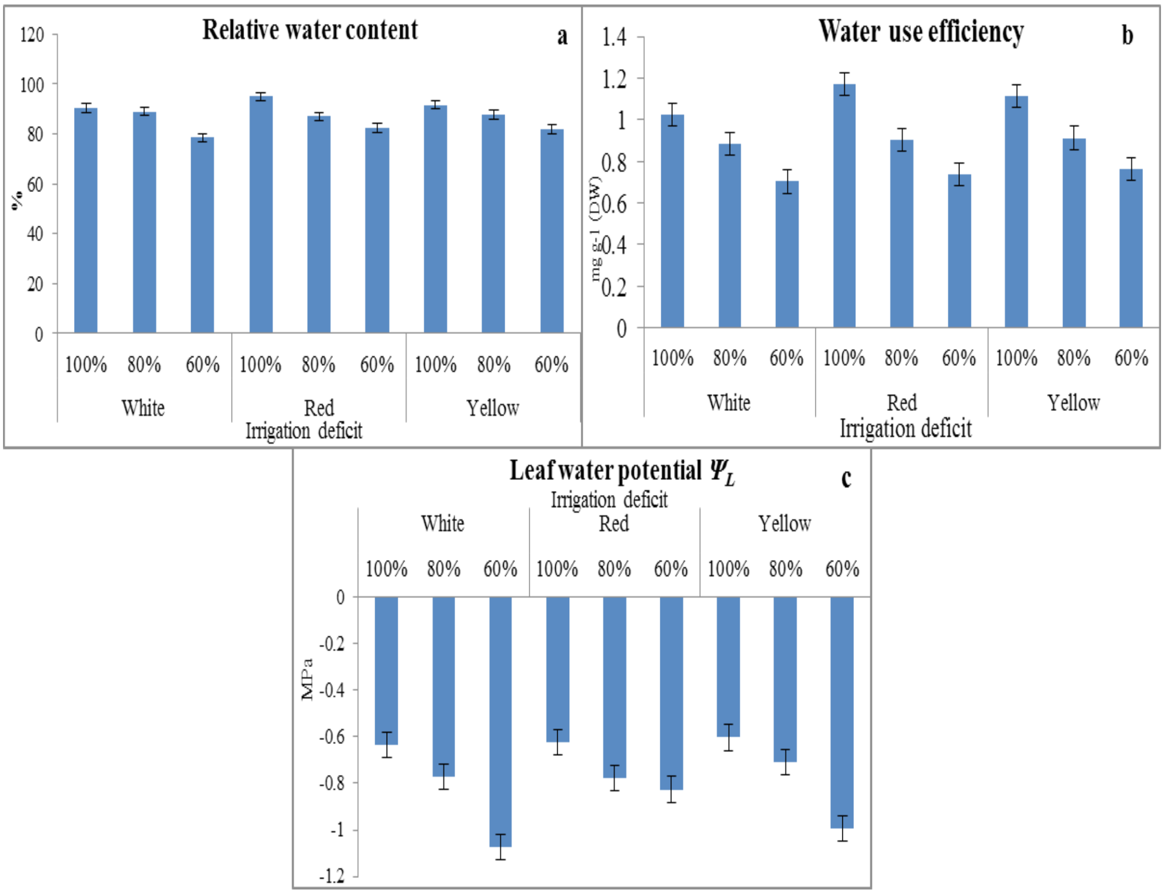

Fig. 4. The leaf water relation measurements ((a) Relative water content (RWC), (b) Water use efficiency (WUE), and (c) Leaf water potential (Ψ_L)); Mean ± S.E. of three Snapdragon cultivars (White, Red and Yellow) in each irrigation treatments (100, 80 and 60% F.C.).

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Conflicts of interest

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استجابة ثلاثة أصناف من نبات حنك السبع لإجهاد الجفاف

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يعد الإجهاد الناتج عن الجفاف أكبر عامل غير حيوي يؤثر سلباً على النمو والإنتاج البستاني. استجابة ثلاثة أصناف من حنك السبع وهي Crackle Pop Exp. (الأبيض والأحمر والأصفر) لنقص المياه من خلال التقييم المورفولوجية والفسيولوجية (تقييم العلاقات المائية للأوراق وتبادل الغازات)، وأصباغ أوراق التمثيل الضوئي، والمكونات المعدنية (الماغنسيوم - الكالسيوم - البوتاسيوم - الفسفور - النيتروجين). تعرضت النباتات لنوعين مختلفين من عجز المياه: الري الجيد بنسبة 100% من القدرة الحقلية (الكنترول) وانخفاض الري بنسبة 80% و60% عن السعة الحقلية (الكنترول) وهي معاملات إجهاد الجفاف. تباينت الأصناف في استجابتها لنقص المياه. تحت معاملة 100% من السعة الحقلية حقق الصنف الأحمر أكبر نمو الخضري، لكن الصنف الأبيض أظهر أكبر إنتاجية للأزهار. أدى الإجهاد المائي إلى انخفاض في أرتفاع النباتات وعدد الأفرع والأوراق والمساحة الورقية في جميع الأصناف. تأخر نمو الجذور في الصنف الأصفر مقارنة بالأصناف الأخرى. تحت ضغط الجفاف أعطى الصنف الأبيض أقصى إنتاجية للارتفاع. ومع ذلك كان الصنف الأصفر هو أدنى عائد. كان للصنف الأحمر معدلات عالية من معدل التمثيل الضوئي وتركيز ثاني أكسيد الكربون بين الخلايا وقيمة كبيرة للأصباغ النباتية والمكونات المعدنية النيتروجين، البوتاسيوم، الماغنسيوم والحالة المائية، في ظل ظروف الإجهاد المواتية ونقص المياه. من بين الأصناف التي تمت دراستها بدا أن الصنف الأحمر أكثر تحملاً لنقص المياه من الصنف الأبيض، كما ينعكس ذلك من خلال ارتفاع الإنتاجية وصفات النمو الخضري.