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Water use efficiency, morpho-physiological and biochemical reactions of some bedding plants to drought stress

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Abstract: The purpose of this experiment is to compare the growth and water consumption efficiency of five garden plants (marigold (*Tagetes erecta* 'Red Brocade'), moss-rose (*Portulaca grandiflora* 'Sun Rose'), dahlia (*Dahlia* sp. 'Double Opra'), gazania (*Gazania splendens* 'New Day'), and Indian blanket (*Gaillardia pulchella.* 'Sun Dance')) during the warmer seasons of the year under various levels of drought stress based on field capacity (FC; 25, 50, 75, and 100 %). The interaction effect of plant × drought stress (FC) on the fresh and dry mass of aerial and underground organs was significant. Decreased water availability resulted in a drop in growth parameters (leaf fresh and dry mass and leaf area). In compared to the growth of aerial organs, root biomass increased in response to drought stress. Marigold, Indian blanket, and dahlia plants had the highest root-to-shoot ratio in extreme stress, i.e., FC 25 %. The plant × drought stress interaction significantly influenced flower number, whereas flower diameter was influenced by the main effect of plant and drought stress (not their interaction). The FC 100 % and FC 25 % treatments had the highest and the lowest accumulations of proline and soluble sugars, respectively. Moss-rose, gazania, and marigold ornamental plants had the highest water use efficiency at 75 %, followed by Dahlia at 50 % and moss-rose at 25 %.

Key words: bedding plants; deficit irrigation; root to shoot ratio membrane; peroxidation; photosynthetic capacity

Učinkovitost izrabe vode, morfološki, fiziološki in biokemijski odziv nekaterih okrasnih rastlin na sušni stress

Izvleček: Namen poskusa je bil primerjati rast in učinkovitost izrabe vode petih okrasnih rastlin (žametnice (*Tagetes erecta* 'Red Brocade'), tolščaka (*Portulaca grandiflora* 'Sun Rose'), dalije (*Dahlia* sp. 'Double Opra'), gazanije (*Gazania splendens* 'New Day'), in gailardije (*Gaillardia pulchella* 'Sun Dance') v toplejši rastni sezoni leta pri različnih ravneh sušnega stresa izzvanega z različno poljsko kapaciteto (FC; 25, 50, 75, in 100 %). Vzajemni učinek vrste rastline in sušnega stresa (FC) na svežo in suho maso nadzemnih in podzemnih organov rastlin je bil značilen. Zmanjšana dostopnost vode je povzročila upad parametrov rasti (sveže in suhe mase listov, listne površine). V primerjavi z rastjo nadzemnih organov se je biomasa korenina povečala kot odziv na sušni stress. Žametnica, gailardija in dalija so imele največje razmerje korenine:poganjki pri ekstremnem sušnem stresu, pri FC 25 %. Učinek sušnega stresa je značilno zmanjšal število cvetov in premer cveta pri vseh obravnavanih rastlinah. Obravnavanji s FC 100 % in FC 25 % sta povzročili največjo in najmanjšo kopičenje prolina in topnih sladkorjev v rastlinah. Tolščak, gazanija in žametnica so imele največjo učinkovitost izrabe vode pri FC 75 %, njim je sledila dalija pri FC 50 % in gailardija pri FC 25 %.

Ključne besede: okrasne rastline; deficitno namakanje; razmerje korenina:poganjek; peroksidacija membrane; velikost fotosinteze

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1 INTRODUCTION

Among the most significant environmental stresses affecting the growth and development of agricultural products are climate change and abnormal weather conditions such as drought, long-term hot temperatures, and storms (Wang et al., 2018). Drought stress has the greatest detrimental effects on the global growth and development of crops compared to other environmental stresses. According to the predictions of experts regarding the rising trend of air temperature (up to a 5 °C increase in the coming years), long and dry summers, and a decrease in precipitation (Giordano et al., 2021), it is crucial to choose appropriate strategies, such as screening and cultivating plants with improved water efficiency. Herbaceous bedding plants perform an essential role in parks as well as other green places. The development of high-quality bedding plants is one of the primary priorities of ornamental plant producers. Nevertheless, due to the shallow growth of their roots and high evapotranspiration on the one hand, and the scarcity of water resources in arid and semiarid regions on the other, the production of these plants is perpetually hindered. Several studies have investigated the impact of drought stress on the growth and development of agricultural and horticultural crops such as spiraea, pittosporum (Elansary and Salem, 2015), bougainvillea (Cirillo et al., 2017), callistemon (Álvarez and Sánchez-Blanco 2015), laurus and thunbergia (Toscano et al., 2023), but little is known about the morphological, physiological, biochemical, and water consumption efficiency of herbaceous ornamental plants, particularly when comparing bedding ornamental plants grown under low irrigation conditions.

Drought stress typically disrupts physiological and biochemical processes, resulting in reduced plant growth and performance (Talbi et al., 2020). At the morphological, physiological, and biochemical levels, plants have a variety of actions (mechanisms) in response to drought stress (Larkunthod et al., 2018; Cal et al., 2019). The aforementioned reactions will vary according to the plant species, growth stage, severity of stress, and length of exposure (Mahajan and Tuteja, 2005). Some species elongate their roots to absorb more water and increase the root-to-shoot ratio (Asrar and Elhindi, 2011). This reaction or mechanism preserves the plant's water status and enables photosynthetic processes to continue during drought stress. In a study comparing the responses of geraniums and impatiens to drought stress, the root length of both species increased; however, plant height and the number of flowers per plant decreased solely in the impatient species (Chyliski et al., 2007).

Water use efficiency is one of the most important considerations when selecting plants for areas with limited water and high temperatures throughout the developmental phase. Many reactions and mechanisms influence the efficiency of a plant's water consumption, including cuticle thickness, leaf angle, leaf surface, stomatal opening and closing, root-to-stem ratio, etc. (Mahajan et al., 2005; Giordano et al., 2021). Despite the fact that stomata closure reduces gas exchange and photosynthesis, water consumption efficiency increases. Water use efficiency regulates the relationship between transpiration and photosynthesis. Improved water use efficiency is one mechanism by which plants adapt to drought stress, whereas lower water use efficiency is characteristic of sensitive plants (Jin et al., 2018). Depending on genotype and stress level, water use efficiency can often decline, increase, or remain constant (Cameron et al., 2006). In consideration of this, it is critical to study the water consumption efficiency of ornamental plants under low irrigation conditions.

Many experiments have been conducted on horticultural plants in regards to drought stress; however, the number of these studies on bedding ornamental plants is quite limited; despite their importance to the health of today's industrial and crowded societies, they have received surprisingly little attention. The purpose of this study is to identify the most productive plant based on biochemical parameters and water consumption efficiency by comparing the morphological and biochemical responses of the most important bedding plants to drought stress in an outdoor environment whose growing season (late spring and summer) corresponds with the onset of heat.

2 MATERIALS AND METHODS

2.1 PLANT MATERIAL AND GROWTH CONDITIONS

The reactions to drought of five bedding ornamental flowers, including Indian blanket (*Gaillardia pulchella* 'Sun Dance'), marigold (*Tagetes erecta* 'Red Brocade'), moss rose (*Portulaca grandiflora* 'Sun Rose'), gazania (*Gazania splendens* 'New Day'), and dahlia (*Dahlia* sp. 'Double Opra'), which grow during the hottest seasons of the year, i.e., late spring to late summer, are investigated. These flowers are planted in both pots and outdoor gardens. Four-leaf seedlings of the above-mentioned plants were transplanted into 5-liter pots containing loam soil (Table 1), and two weeks later, drought stress treatments were provided based on the pots' soil moisture content.

The location of the experiment is located between 35 degrees 58 minutes to 39 degrees 47 minutes north latitude (from the equator) and 44 degrees 3 minutes to

Table 1: Physicochemical characteristics of soil substrates used in the experiment

EC (dS m^{-1})	pH	OM (%)	Clay (%)	Silt (%)	Sand (%)	Soil texture	Bulk density (g cm^{-3})	Specific gravity (g cm^{-3})
0.52	6.7	1.4	29	58	13	Loam	1.5	2.7

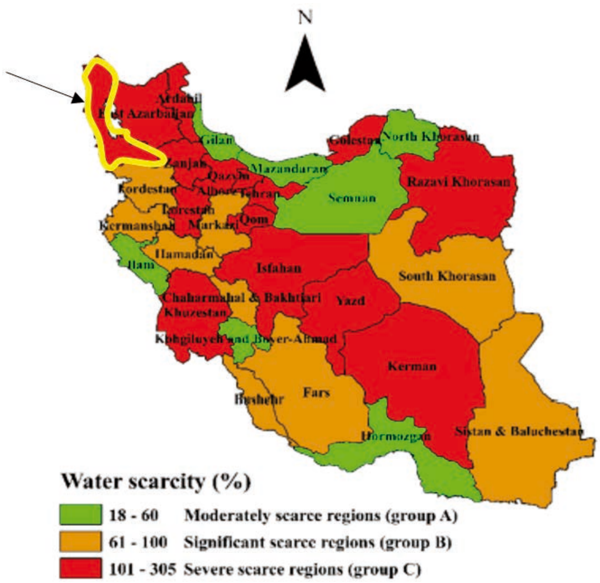

Figure 1: Map of dry climates in Iran (yellow outline (arrow) shows the experimental site) (Qasemipour et al., 2020)

47 degrees 23 minutes longitude from the Greenwich meridian. The height above sea level is 1358 meters (Iran Hydrology, Meteorological Information Bank) (Figure 1).

All cultivated plants were subjected to five levels of field capacity (FC) during the experiment, including FC 100 % (control or no stress), FC 75 % (low stress), FC 50 % (moderate stress), and FC 25 % (severe stress) (Figure 2).

Throughout the cultivation period, environmental characteristics were observed (Table 2). This experiment was carried out as a factorial experiment based on completely randomized design. Each treatment consists of three repetitions, and each repetition has three pots, for a total of 180 pots.

Table 2: Environmental parameters of the experimental site during cultivation

	Mean temperature (˚C)		Relative humidity (%)
Month	Day	Night	
April	13	7	60
May	22	15	38
June	25.8	17	14
July	28	19	10
August	30	19	5
September	25	16	7

2.2 DROUGHT STRESS TREATMENTS (FIELD CAPACITY)

Depending on the pot's field capacity or the percentage of soil moisture, various levels of drought stress were applied. Five pots containing substrate soil were irrigated to saturation with irrigation water, then tightly covered with aluminum foil (to prevent water evaporation) and weighed after the gravity (saturated) water exited. After leaving the saturated water (at 105 °C for 72 hours), the wet and dry mass of the substrate soil were determined, and the obtained humidity was determined to be 100 percent of field capacity (Henry, 1990). Additional treatments were computed using the control's (FC100 %) moisture content (Heidari et al., 2016). Before being irrigated, each pot in the experiment was precisely weighed,

Figure 2: A view of some potted bedding plants under various drought stress or FC levels (Indian blanket (left) and marigold (right))

and the mass loss in each sample is due to the plants' stress levels.

2.3 GROWTH PARAMETERS

At the end of the growth period, all plants were removed from the cultivated beds, and their aerial and underground organs were separated. Exact measurements were taken of root length (the longest root), root volume, the number of leaves per plant, and the fresh and dry mass of roots and aerial organs.

2.4 PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS

Fully developed mature leaves were fixed in liquid nitrogen and stored at -80 °C. The effects of drought stress on the production of osmolytes or compatible metabolites in leaves, such as soluble sugar and proline amino acid, were investigated. For each plant, 0.5 g of leaf tissue was homogenized with 10 ml of 3 % sulfosalicylic acid before being analyzed for proline content. It was heated in a water bath at 100 °C for one hour with 2 ml of glacial acetic acid and 2 ml of centrifuged ninhydrin acid. After cooling the samples, 4 ml of toluene was added to each vial, and the vials were shaken for 15 to 20 seconds. Samples were evaluated for proline content by measuring the 520 nm absorbance of each sample and comparing it to a standard curve for proline concentration (Bates, 1973). Anthrone digested leaf samples with 70 % ethanol, mixed them with the supernatant, and measured absorbance at a wavelength of 625 nm to determine the total soluble sugar content of the leaf sample. As a reference, glucose was used in the preparation of the standard (Irigoyen et al., 1992).

Ion leakage and peroxidation of the leaf cell membrane were measured as indicators of cell and leaf tissue destruction caused by drought stress. Leaf ionic leakage was measured by comparing the electrical conductivity ratio (L1/L2) of leaf tissue under normal conditions (L1) (20 °C for 2 hours) and at high temperature (autoclave for 20 minutes at 121 °C) (L2) (Lutts et al., 1996). Lipid peroxidation of the leaf membrane was also performed using a spectrophotometric method, as was the determination of malonaldehyde content using thiobarbituric acid (TBA) and absorption of the resulting supernatant at wavelengths of 440, 532, and 600 nm (Valentovic et al., 2006).

Photosynthetic pigments, including chlorophyll a, b, and total, as well as carotenoid content of leaves, were measured using a spectrophotometer (Perkin Elmer, UV/VIS, Lambda 25) at 645 and 663 nm (chlorophyll a and b) and 470 nm (carotenoids).

Due to the direct relationship between drought stress and plant calcium uptake, as well as the importance of calcium in the growth and physiology of ornamental plants, the calcium content of the leaf was determined using an atomic absorption device.

2.5 THE RELATIVE WATER CONTENT (RWC) AND WATER USE EFFICIENCY

To determine the relative water content of leaves, young mature leaves from each plant were cut into one-centimeter squares, and 10 pieces of leaves were selected and weighed (FM; fresh mass); The samples were then transferred to petri dishes containing distilled water at 4 degrees Celsius for four hours, after which their mass was measured once more (TM; Turgor Mass). The samples were then placed in an oven at 72 °C for 72 hours and reweighed (DM; dry mass) (Ritchie et al., 1990). The relative water content of the leaf was then estimated using the following formula:

$$RWC = \frac{FM - DM}{SM - DM} \times 100$$

Water use efficiency was also evaluated based on the amount of dry matter generated by each plant per unit of water consumed by that plant in response to various soil stresses or irrigation regimes (Boyer, 1996).

2.6 EXPERIMENTAL DESIGN AND DATA ANALYSIS

This study was analyzed with two factors: bedding plant and irrigation regime, using factorial trials based on a completely random design. SAS Software version 9.1 was used to analyze the data, and Tukey's test was used to compare the means.

3 RESULTS AND DISCUSSION

3.1 GROWTH PARAMETERS

Fresh and dry mass of aerial and underground organs were significantly affected by the interaction effect of plant × drought stress (FC). Decreasing the plant's access to water led to a decrease in growth and developmental parameters, i.e., leaf fresh and dry mass and leaf area; also, the highest leaf area per plant was observed in gazania and marigold plants in the control treatment, or FC 100 %. Unlike the growth of aerial organs, the fresh and dry mass of the root showed an upward trend in response to water stress (Table 3). In other words, at the same time as the severity of drought stress increased, root growth (root fresh and dry mass and root length) of bedding plants increased (probably to search for water needed by the plant). Based on the results of mean comparisons, the highest fresh and dry mass of roots was obtained in the Indian blanket plant at FC 25 %, and the highest root growth was obtained in the marigold flower at FC 25 %.

The root-to-stem ratio, as one of the morphological reactions that is strongly influenced by the plant's ability to access water, was balanced in most plants under 75 to 100 %, while with the increase in stress level, i.e., a 50 % decrease in substrate moisture, the root-to-stem ratio increased. The highest root-to-stem ratio in severe stress, i.e., 25 % FC, was observed in marigold, Indian blanket, and dahlia plants, respectively (Figure 3).

In this experiment, the plant × drought stress interaction had a significant effect on the number of flowers, but it had no effect on the floral diameter; only the plant type and drought stress had a significant effect on this important ornamental attribute. According to the results, the number of flowers per plant fell as plant access to water reduced, while the minimum number of flow-

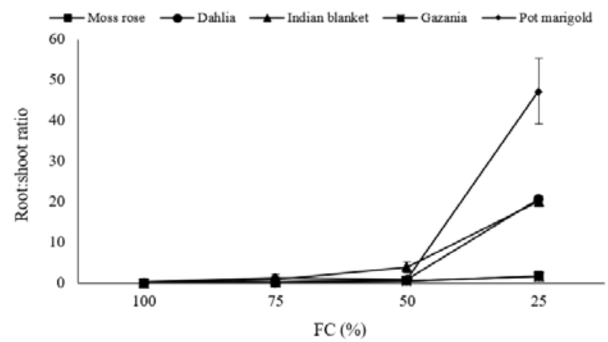

Figure 3: Root to shoot ratio of some bedding plants under various levels of drought stress (field capacity)

Table 3: Growth parameters of some bedding plants under various drought stress levels (FC)

Bedding plant	FC (%)*	Leaf FM** (mg/plant)	Leaf DM*** (mg/plant)	Root FM (mg/plant)	Root DM (mg/plant)	Root length (cm)	Leaf area (mm^2/plant)
Moss-rose	100	5.36 efg****	0.68 ghij	1.67 f	0.04 e	9.67 ij	9.33 gh
	75	2.13 fg	0.38 hij	0.72 f	0.11 e	15.83 fghij	7.25 h
	50	1.70 fg	0.27 ij	0.38 f	0.12 e	18.67 defghi	5.17 h
	25	0.96 fg	0.16 j	0.32 f	0.28 e	30.33 bc	3.95 h
Dahlia	100	13.65 c	3.76 b	16.76 cd	0.17 e	8.20 hij	1138.95 b
	75	11.85 cd	2.32cd	8.45 def	0.60 e	10.22 defgh	608.06 c
	50	6.05 ef	1.26 efgh	1.99 f f	2.38 cde	19.17 bc	443.82 cd
	25	1.54 fg	0.18 j	0.40 f	6.36 b	29.83 j	126.71 efgh
Indian blanket	100	28.99 a	5.45 a	5.47 f	0.61 e	23.17 cdef	352.45 cde
	75	11.85 cd	3.67 b	13.91 cde	3.32 cd	25.83 cd	273.97 defgh
	50	7.54 de	2.07 de	40.05 b	6.89 b	32.42 bc	179.69 defgh
	25	2.04 fg	0.27 ij	55.80 a	10.17 a	37.00 ab	77.46 efgh
Gazania	100	8.54 cde	3.21 b	4.02 f	0.18 e	13.79 ghij	1485.01 a
	75	5.85 efg	1.67 def	1.46 f	0.33 e	16.50 efghij	328.05 cdef
	50	3.57 efg	1.14 fghi	1.03 f	0.44 e	17.33 efghij	292.67 defgh
	25	1.33 fg	0.51 ghij	0.59 f	0.78 e	19.93 defg	23.72 fgh
Marigold	100	20.55 b	3.04 bc	19.44 c	0.17 e	14.33 fghij	1485.01 a
	75	7.93 de	0.91 fghij	8.05 ef	0.56 e	30.17 bc	328.05 cdef
	50	4.89 efg	1.35 efg	6.16 ef	0.93 de	25.67 cde	323.75 cdefg
	25	0.63 g	0.10 j	1.53 f	4.77 bc	45.00 a	23.06 fgh

* FC: Field capacity
** FM: Fresh mass
*** DM: Dry mass
**** Means with the same letter in each column don't have significant difference

ers per plant was obtained at FC 50 % and particularly at FC 25 %. (Figure 4). According to the mean comparisons, the least possible irrigation for marigold and Indian blanket is FC 75 %; however, for moss rose, dahlia, and gazania, it is FC 50 %.

One of the key indicators of flowering bedding plants, flower diameter, was significantly impacted by the plant and various levels of drought stress. As shown in Figure 5A, the relationship between floral diameter and the degree of drought stress is downward and linear. The genotype had a complete impact on flower diameter, with marigolds, gazanias, and dahlias having the highest flower diameters, respectively (Figure 5B).

The interaction between plant genotype and drought stress had a significant impact on the content of photosynthetic pigments, including chlorophylls a, b, and total as well as carotenoids. Based on the findings, all bedding plants showed a decreasing trend in photosynthetic pigment content as drought stress increased. Moss-rose (79 %), Indian blanket (72 %), marigold (68 %), gazania (46 %), and dahlia (40 %) had the highest decrease in total chlorophyll content (the sum of chlorophyll a and b) under severe drought stress (FC 25 %) compared to the control (FC 100 %) (Table 4).

3.2 BIOCHEMICAL AND PHYSIOLOGICAL PARAMETERS

One of the most significant metabolic responses of

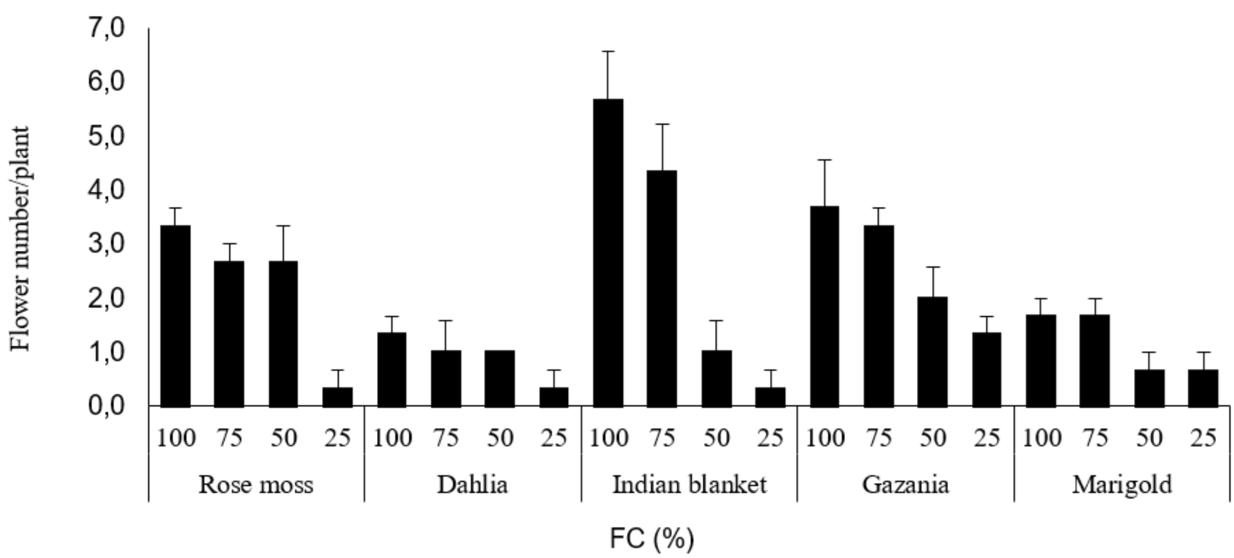

Figure 4: The number of flowers per plant of some bedding plants under various drought stress (FC level)

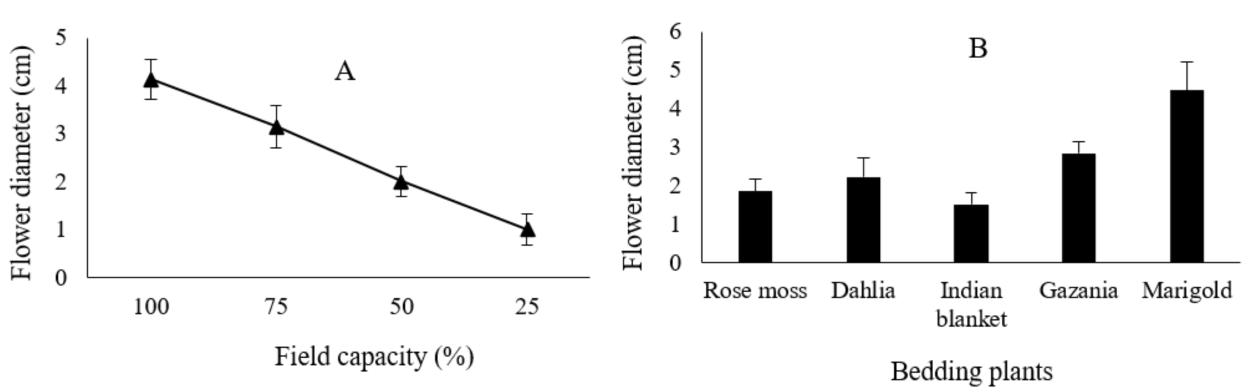

Figure 5: The diameter of bedding plant flowers under various drought stress levels (a) and plant genotype (b)

Table 4: Photosynthetic pigments of some bedding plants under various drought stress levels

Bedding plant	FC*	Chlorophyll a (mg g FM^{-1})	Chlorophyll b (mg g FM^{-1})	Total Chlorophyll (mg g FM^{-1})	Carotenoids (mg g FM^{-1})
Moss-rose	100	0.00034 b**	0.000423 de	0.00073 f	0.0180 i
	75	0.00018 b	0.000249 fg	0.00042 gh	0.0120 ij
	50	0.00013 b	0.000102 hi	0.00021 h	0.0063 j
	25	0.00005 b	0.000066 b	0.00015 h	0.0033 j
Dahlia	100	0.00478 a	0.000801 a	0.00146 a	0.0850 a
	75	0.00068 b	0.000598 bc	0.00123 abc	0.0750 ab
	50	0.00060 b	0.000545 bcd	0.00115 bc	0.0657 bc
	25	0.00045 b	0.000491 cd	0.00087 def	0.0493 e
Indian blanket	100	0.00081 b	0.000536 bcd	0.00134 ab	0.0610 cd
	75	0.00059 b	0.000448 de	0.00106 cde	0.0507 de
	50	0.00047 b	0.000274 fg	0.00075 f	0.0430 efg
	25	0.00024 b	0.000034 i	0.00038 gh	0.0230 hi
Gazania	100	0.00071 b	0.000551 bcd	0.00115 bc	0.0647 bc
	75	0.00049 b	0.000447 de	0.00085 fe	0.0457 ef
	50	0.00044 b	0.000331 ef	0.00077 f	0.0410 efg
	25	0.00034 b	0.000138 fgi	0.00062 fg	0.0317 gh
Marigold	100	0.00043 b	0.000761 a	0.00114 bcd	0.0523 de
	75	0.00037 b	0.000674 ab	0.00104 cde	0.0357 fg
	50	0.00029 b	0.000528 bcd	0.00082 fe	0.0207 hi
	25	0.00013 b	0.000231 fgh	0.00036 gh	0.0130 ij

* Field capacity
** Means with the same letter in each column don't have significant difference

plants to increasing environmental stresses, such as insufficient irrigation, is the accumulation of proline and soluble sugars. As shown in Table 5, the level of soluble sugars and proline was lowest in the control treatment (FC 100 %), or no stress, and the highest in the FC25 % treatment, or severe stress, in all the plants under study. The moss-rose and gazania bedding flowers showed the biggest increases in proline production under severe stress (compared to the control), respectively. The percentage of leaf ion leakage, a sign indicating drought stress is disrupting the cell membrane, significantly rose as the severity of the drought stress increased.

Because of the passive uptake mechanism, humidity and the plant's access to water have a significant impact on the plant's calcium uptake. From this, we may conclude that 100 % FC yielded the highest calcium content in all bedding plants (control). However, there was a decreasing trend of calcium percentage in leaves with increasing stress intensity, with the lowest calcium percentage recorded at 25 % FC (Figure 6). Marigolds (92 %) and gazania (84 %), among the plants studied, showed the greatest reduction in calcium absorption under severe stress (FC 25 %) compared to the control (FC 100 %), and dahlias (48 %), the least.

In the absence of stress, the relative water content of the leaves of moss-rose, dahlia, Indian blanket, gazania, and marigold plants was 86.5, 70, 97, 93.5, and 81 %, respectively. However, as deficit irrigation increased, the relative water content of the leaves decreased, resulting in a decrease of 58, 92, 39, 42, and 63 % in the cases of severe stress (25 % FC) (Figure 7). Low and medium stressors showed no significant difference in any of the studied plants.

3.3 WATER USE EFFICIENCY

Depending on the level of stress and the plant species, the water-use efficiency followed a completely different pattern (Figure 8). The ornamental plants with the highest water consumption efficiency were moss rose, gazania, and marigold (75 %), followed by dahlia (50 %) and moss rose (25 %). The results of this experiment indicate that in arid and water-scarce regions, the regulation

Table 5: Biochemical responses of some bedding plants to various drought stress levels

Bedding plant	FC*	Soluble sugars (µg FM⁻¹)	Proline (µg g FM⁻¹)	Ion leakage (%)
Moss-rose	100	405.00 d**	8.27 j	44.03 de
	75	460.67 c	14.13 hij	51.62 bc
	50	500.33 b	36.13 fg	54.56 b
	25	524.33 a	66.50 d	63.98 a
Dahlia	100	48.90 fgh	5.53 j	29.78 hi
	75	56.97 efgh	7.87 j	33.04 g
	50	61.27 efg	13.21 hij	35.34 g
	25	72.07 e	26.92 ghi	40.77 ef
Indian blanket	100	46.10 gh	10.15 j	28.05 hi
	75	48.23 gh	13.21 hij	36.04 fg
	50	57.57 efgh	47.40 ef	41.97 de
	25	67.80 ef	149.50 b	47.04 cd
Gazania	100	39.13 h	12.00 ij	23.77 j
	75	44.43 gh	18.93 hij	26.51 ij
	50	46.93 gh	29.21 gh	29.27 g
	25	52.53 fgh	181.34 a	35.32 hi
Marigold	100	43.90 gh	11.93 ij	10.03 i
	75	46.00 gh	19.17 hij	11.96 kl
	50	57.97 efgh	53.67 de	14.03 kl
	25	73.73 e	124.36 c	16.51 k

* Field capacity
** Means with the same letter in each column don't have significant difference

of water use for the production of dry matter is crucial. In other words, neither the control treatment (without stress) nor the plants with the highest water use showed the highest water use efficiency. As a result of the water storage organs present in plants such as moss rose, the highest water use efficiency was attained with the lowest water consumption.

4 DISCUSSION

Ornamental bedding plants are commonly impacted by drought, which has a negative impact on plant growth and flowering and, ultimately, on their aesthetic value. To avoid losing their attractive qualities, plants that can withstand water scarcity must be chosen. In order to choose the best plants for urban environments and to develop new cultivars that would be better suited to urban conditions, ornamental growers and breeding programs may benefit from experiments for drought tolerance that are based on measurements of certain factors relevant to the plant's water status. There isn't much knowledge on the application of selection criteria when choosing the right decorative plant species for urban green spaces or when developing plants to be more tolerant of water deficits. The rate of growth or survival of plants is frequently studied to determine how well they can handle drought stress. A more straightforward and efficient strategy may be indirect selection for drought tolerance in breeding, utilizing physiological or biochemical traits as markers. Leaf cell membrane stability, relative water content, and proline content are important factors for evaluating plant

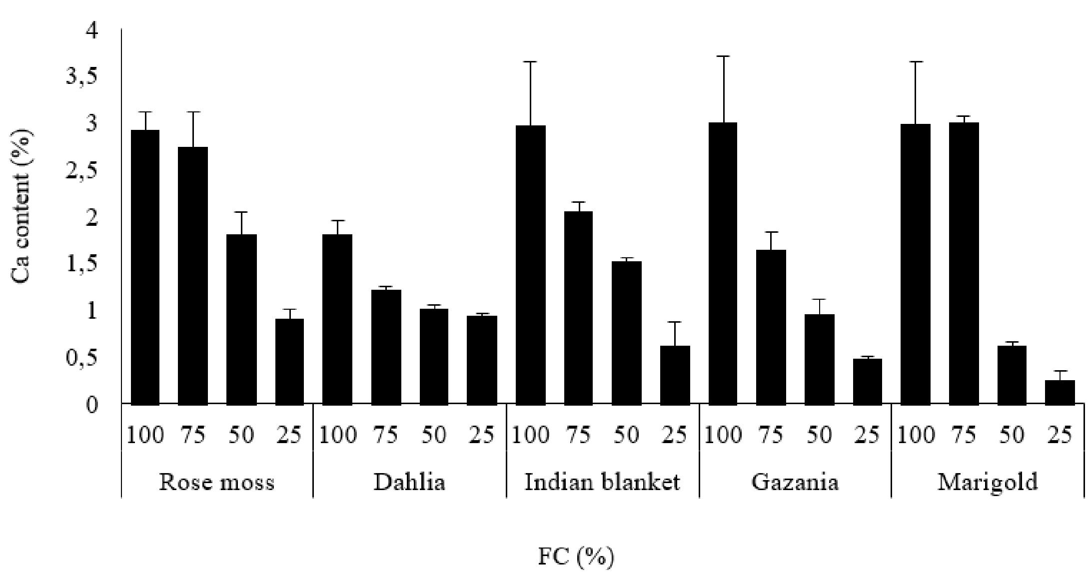

Figure 6: Leaf calcium content of some bedding plants under different drought stress (FC) levels

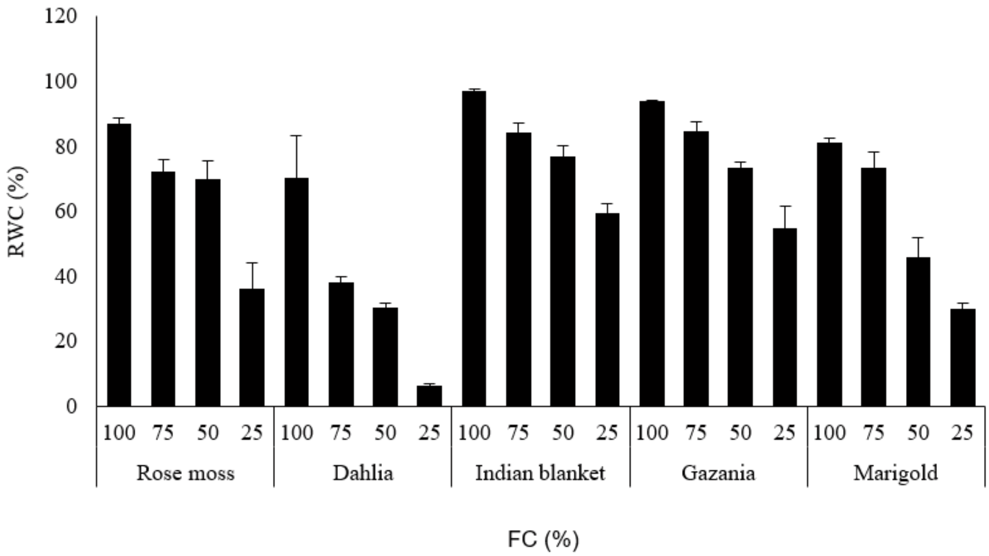

Figure 7: The leaf relative water content (RWC) of some bedding ornamental plants under different drought stress levels

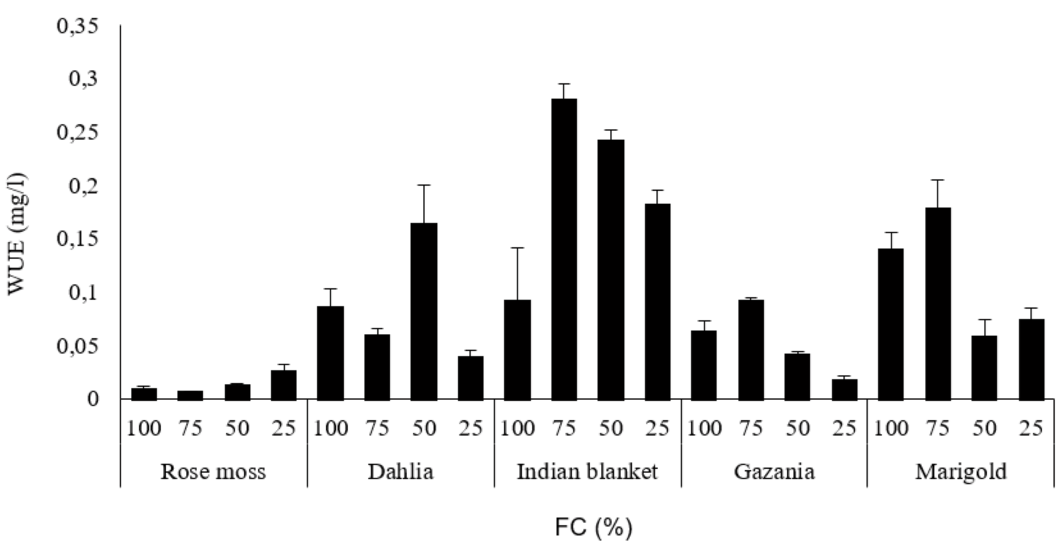

Figure 8: Water use efficiency of some bedding plants under various drought stress levels

reactions to drought stress (Gzik 1996; Quilambo 2004; Grant 2012). Here, we describe an effort to measure the morphological, physiological, and biochemical responses of five popular bedding plants to an imposed water stress. The goal was to determine which of these bedding plants can respond better to water deficit conditions for urban settings. Our investigations on bedding plants support previous findings that different plant species respond differently to drought (Volaire 2003; Kumar et al., 2018).

As previously described, the responses of the aerial (leaf) and underground (root) organs of bedding plants to drought stress showed a completely different pattern. In fact, the investigated bedding plants decreased the fresh and dry mass of the leaves and the leaf area by reducing the plant's access to water, while increasing the fresh and dry mass of the roots and the root length. Reducing leaf area or the phenomenon of leaf area adjustment (to reduce evapotranspiration) and increasing root growth and the root-to-shoot ratio (to improve water absorption) in drought-stressed plants are effective strategies for managing water absorption and consumption (Mahajan and Tuteja, 2005). Also some biochemical mechanisms are involved in conferring tolerance to drought stress in plants. One of the common mechanisms in plants under stress is an increase in the antioxidant activity to limit the oxidative damage, however, numerous factors affect the potential of antioxidant induction (Keyghobadi et al., 2020). The diameter of the flower and the number of flowers are the most significant factors that influence the drought tolerance of bedding plants. Marigold and Indian blanket require 75 % FC for optimal flower development, whereas gazania, rose moss, and dahlia only need 50 % FC. There is a close relationship between the morphological characteristics of plants and their drought tolerance (Bhusal et al., 2021). Rose moss, because of its fleshy leaves (which retain more water), gazania, and dahlia, because of their hairy leaves, have probably been capable of withstanding drought stress better. The decrease in flower diameter with increasing drought stress may also be caused by a drop in cell turgor induced by a shortage of water, which in turn leads to a reduction in cell development and, eventually, a loss in flower diameter. Consequently, the leaf water status, or the leaf's RWC (Figure 5), describes the relationship between plant water content and flower diameters under various drought stress or FC levels. Also, the observed decrease in growth characters may be the result of a decrease in the photosynthesis rate under drought stress, which can be attributed to the closure of stomata or a decrease in the leaf area in response to drought stress. Furthermore, the reduction in growth may be due to the fact that a lot of energy is used to produce enzymes and osmolytes. The decrease in the leaf area under drought conditions can be due to stomatal closure, and reduced water potential, leaf cell turgor pressure, photosynthesis, chlorophyll content, and Rubisco's carboxylase activity. A decrease in the growth rate of plant organs and leaf area due to increased drought stress can also be the result of depressed biosynthesis of growth hormones and induction of inhibitors such as abscisic acid (Keyghobadi et al., 2020).

The results of the current study are in agreement with the outcomes of other investigations in several crops (Toupchi Khosrowshahi et al. 2018; Rafi et al., 2019; Pourasadollahi et al. 2019). Also the existence of genetic diversity for tolerance to stress conditions has been frequently reported in other plant species (Hosseini Boldaji et al. 2012; Zebarjadi et al. 2012). In another study, drought stress effected the growth and antioxidant enzyme activities of *Pandanus* plants, drought stress has significantly affected the growth of *Pandanus* plants, such as LRWC, root-to-shoot ratio, shoot and root biomass, and REL, and led to an accumulation of ROS that damage cell membranes (Mohd Amnan, et al., 2021)

In addition to morphological responses to drought stress, biochemical and physiological responses also play a significant role in improving the plant's status under stress conditions (Hura et al., 2022). Drought stress disturbs physiological and biochemical processes in plants, including cell membrane, disrupting transportation of solutes, photosynthesis rate, nutrient uptake, translocation, and causes electron leakage and excessive accumulation of reactive oxygen species (ROS) (Nalina et al., 2021). Drought stress as an abiotic stress has likely caused an increase in the destruction of the cell membrane and, consequently, an increase in ion leakage (Table 4) and the destruction of photosynthetic pigments, i.e., chlorophyll a, b, and carotenoids, by increasing the production of free radicals. Drought stress changes photosynthetic pigment content. Photosynthetic pigments play important roles in harvesting light. The content of both chlorophyll a and b changed under drought stress. It is generally accepted that the maintenance of cell membrane integrity and stability under water stress conditions is a major component of drought tolerance in plants (Mombeni and Abbasi, 2019). The amount of chlorophyll, the most fundamental photosynthetic property, is significantly altered by water, serving as a unique indicator of chlorophyll photooxidation and degradation (Anjum et al., 2011). Decrease in the photosynthesis rate under drought stress, which can be attributed to the closure of stomata or a decrease in the leaf area in response to drought stress (Bijalwan et al., 2022). However, the increase in the level of compatible metabolites, i.e., proline and soluble sugars, concurrently with the increase in the level of drought stress (Table 4), prompted another biochemical reaction of bedding plants, known as osmotic adjustment (Mahajan and Tuteja, 2005), in order to maintain the plant's stability and absorption capability under low FC levels of the substrate, i.e., 25 and 50 % FC levels. Carbohydrates, the product of photosynthesis, provide a growth and maintenance substrate for non-photosynthetic tissues (Abdallah et al., 2018). Several factors affect sugar transport through the phloem (source, sink, and route between the two), impacting the source-sink interaction (Korner, 2015).The rate of photosynthesis and the amount of sucrose in leaves affect assimilate export from source to sink (Yu et al., 2015). Dry weather reduces photosynthesis and sugar concentration, slowing water transport. Drought also hinders the sink's capacity to utilize assimilates effectively. Drought significantly affects sugar metabolism and phloem loading. On the other hand, drought may change nutrient contents (e.g., sugars and amino acids) (Bijalwan et al., 2022). Often, plant cell membranes are subjected to changes associated with increase in permeability and loss of integrity under environmental stresses. The role of proline in response to drought stress include a very important part in the biosynthesis of cell-wall matrix proteins, such as extensins, that have important roles in cell morphology and provide mechanical support for the cell under stressed conditions. A neglected aspect of proline metabolism concerns its importance during the stress relief phase. In fact, its rapid oxidation is equally important in recycling the free amino acid accumulated during the stress conditions with the production of reducing power, amino nitrogen and energy, all needed in the restoration of cellular homeostasis during the recovery from drought stress (Mombeni and Abbasi, 2019).

In accordance with the results obtained with, in study physiological changes purslane (*Portulaca oleracea* L.) under drought stress, was observed drought treatment for 10 d significantly increased MDA, proline, EL, O_2radical dot–, and activities of SOD and POD. Also drought stress decreased LWC and chlorophyll content. This study indicated that the purslane has a great capability to cope with drought stress and activate many physiological mechanisms, which allow more efficient recovery during rehydration (Jin et al., 2015).

This study indicated a decline in calcium uptake as drought stress increased, particularly at extreme levels of drought stress (FC 25 %). Under normal circumstances, plants have the proper cellular turgor and absorption of nutrient ions, whereas water shortage conditions hamper the absorption of nutrients and consequently prevent shoot and root development. Under drought stress, the nutritional constraints are created by the reduction in the elemental uptake and consequently reduces the production of aerial organs. Therefore, under stress and low cellular turgor, the allocation ratio of the nutrients to roots increases against aboveground parts and the plant will not be able to continue to its normal growth (Keyghobadi et al., 2020). The fundamental reason for the drop in calcium absorption is the correlation between calcium uptake and the percentage of water in the substrate or the availability of water to the roots. In other words, the process of passive absorption of calcium and its direct relationship with the substrate's water capacity (Marschner, 2011) have led to a decrease in this element's uptake. Calcium is essential for the development and quality of horticultural crops, especially ornamental plants. The decreased uptake of this element reduces the appearance, quality, and durability of flowers, as well as their market value. Consequently, plants with the capacity to absorb water more efficiently under conditions of drought stress will be able to produce flowers of higher quality. All bedding plants displayed the highest calcium uptake under the control condition (FC 100 %); however, rose moss and marigold exhibited the highest calcium uptake at FC 75 %, rose moss at FC 50 %, and dahlia at FC 25 %.

Relative water content (RWC) is identified as one of the essential characteristics to determine leaf water status of genotypes to detect heat or drought tolerance ones. Water use efficiency (WUE) is also introduced as an indirect drought-tolerant cultivar selection method for grain yield under drought stress conditions (Bakhshi, 2021). Decrease of RWC is one of the early symptoms of water deficiency in plant tissues and many researchers have reported decrease in RWC under drought stress (Mombeni and Abbasi, 2019). Under extreme drought stress, rose moss exhibited greater water efficiency than the other evaluated bedding plants, most likely due to its fleshy leaves and capacity to retain water. In contrast, a distinct response was observed in other plants. Indian blanket was shown to have the highest water efficiency at all FC levels, including FC 25 %, which had the highest quantity compared to other plants at the same treatment level. It was revealed that dahlias (FC 50 %), gazanias (FC 75 %), and marigold plants (FC 75 %) had the highest water use efficiency. It has been observed that plants leaf relative water content was greater throughout leaf development and reduced as dry matter accumulated when the leaf matured. Water-use efficiency at the whole-plant level is defined as the ratio of dry matter produced and water consumed (Du et al., 2020). That plants water-use efficiency was higher in limited supplies than in well-watered situations. They linked this improved water efficiency to stomatal closure, which reduces transpiration (Khalid et al., 2019). It is reported that high relative water content is a resistant mechanism to drought, and high relative water content is the result of more osmotic regulation or less elasticity of tissue cell wall. Reported that the electrolyte leakage (EL) from a sensitive maize cultivar increased about 11 % to 54 % more than that of a tolerant cultivar after water stress treatment (Mombeni and Abbasi, 2019).

Due to its increased vegetative growth (Table 3), long stem, and morphological characteristics (leaf hairs), the Indian blanket probably has a higher water consumption efficiency than other assessed plants. As an osmotic regulator and stress moderator, FC 25 %, which endured the most severe drought stress, exhibited a considerable increase in proline content. The results of this experiment are in line with the findings of Chyliński et al. (2007) who compared the resistance and reactions of two ornamental plants, impatiens and geraniums.

5 CONCLUSION

Considering the problem of water shortage in many parts of the world and the little knowledge about growth reactions, especially the efficiency of water consumption in ornamental plants in the under irrigation shortage and drought stress conditions, in the current research, 5 important ornamental plants were investigated. The results of this research clearly showed that the resistance of each plant against drought stress depends on the specific morphological, physiological and biochemical reactions of that plant. In addition, the severity of drought stress is one of the most important factors determining plant selection for water shortage conditions. This study confirms that among the investigated bedding plants, Indian blanket has the greatest potential for cultivation in water-limited environments due to increased biomass production, flower number and water use efficiency. Additionally, comparison and evaluation of the growth responses and water use efficiency of commercial varieties of the studied bedding plants as well as the use of more precise tools or protocols to track the moisture status of the root rhizosphere are among the most critical issues that were not possible in the implementation of the current experiment, consequently, it is suggested that these parameters to be taken into consideration in the following research.

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