

Seed quality, water use efficiency and eco physiological characteristics of *Lallemantia* (*Lallemantia* sp.) species as effected by soil moisture content

Mina ABDOLAHI¹, Saeideh MALEKI FARAHANI^{1, 2}

Received July 15, 2018; accepted June 23, 2019.
Delo je prispelo 15. julija 2018, sprejeto 23. junija 2019.

Seed quality, water use efficiency and eco physiological characteristics of *Lallemantia* (*Lallemantia* sp.) species as effected by soil moisture content

Abstract: This study investigated the effect of drought stress on the yield, water use efficiency (WUE), physiology, and seed quality of two species *Lallemantia* sp. Field experiments with three irrigation regimes were carried out in a split plot factorial in a randomized complete block design with three replications. Treatments included irrigation after 40 %, 60 %, and 100 % depletion of available soil water (ASW) (I_{40} , I_{60} , and I_{100} , respectively) as main plots and *Lallemantia* species *L. iberica* (M. Bieb.) Fisch. & C. A. Mey. (S_1) and *L. royleana* Benth. in Wall (S_2) as subplots. Increment in depletion of ASW (I_{40} to I_{100}) resulted in progressively less chlorophyll *a* content (Chl *a*), open stomata percentage (OS), and leaf area index (LAI). The highest Chl *a* and LAI were found to be 0.0087 mg g⁻¹, and 2.68 mg g⁻¹ leaf mass in I_{40} treatment, respectively, while closed stomata percentage (CS) increased significantly as drought stress increased. The results of this experiment indicated that the appropriate yield of production was obtained in plots which were fully irrigated (I_{40}) for all species of *Lallemantia*; however, the WUE increased as drought stress increased. The interaction of drought stress, *Lallemantia* species with grain yield and WUE was significant.

Key words: *Lallemantia*; drought stress; leaf area; water productivity

Vpliv vsebnosti vode v tleh na kakovost semen, učinkovitost izrabe vode in ekofiziološke lastnosti različnih vrst lallemancije (*Lallemantia* sp.)

Izvleček: V raziskavi so bili preučevani učinki sušnega stresa na pridelek, učinkovitost izrabe vode (WUE), fiziologijo in kakovost semen dveh vrst lallemancije (*Lallemantia* sp.). Poljski poskus s tremi režimi namakanja je bil izveden kot popolni bločni faktorski poskus z deljenkami s tremi ponovitvami. Obravnavanja so obsegala namakanja po 40 %, 60 %, in 100 % zmanjšanju razpoložljive vode v tleh ($ASW_{I_{40}}$, I_{60} , and I_{100}) na glavnih ploskvah in vrste lallemancije, *L. iberica* (M. Bieb.) Fisch. & C. A. Mey. (S_1) in *L. royleana* Benth. in Wall (S_2) na podploskvah. Povečanje pomanjkanja vode (iz I_{40} na I_{100}) je povzročilo progresivno zmanjšanje vsebnosti klorofila *a*, zmanjšanje odstotka odprtih listnih rež (OS), in zmanjšanje indeksa listne površine (LAI). Največji vrednosti vsebnosti klorofila *a* in indeksa listne površine sta bili izmerjeni, 0,0087 mg g⁻¹, in 2,68 mg g⁻¹ listne mase, pri obravnavanju I_{40} medtem, ko se je odstotek zaprtih rež (CS) z večanjem sušnega stresa značilno povečal. Rezultati raziskave kažejo, da je bil najboljši pridelek dosežen na dobro namakanih ploskvah (I_{40}) pri obeh vrstah lallemancije a učinkovitost izrabe vode se je s sušnim stresom povečevala. Medsebojni vpliv sušnega stresa, vrst lallemancije, pridelka zrnja in učinkovitosti izrabe vode je bil dokaj velik.

Ključne besede: *Lallemantia*; sušni stress; listna površina; učinkovitost izrabe vode

¹ Shahed University, Department of Crop Production and Plant Breeding, Tehran, Iran

² Corresponding author, e-mail: maleki@shahed.ac.ir

1 INTRODUCTION

Lallemantia, commonly known as Balangu, belongs to the family of Labiatae and is represented by five species: *L. iberica* (M. Bieb.) Fisch. & C. A. Mey., *L. baldshuanica* Gontsch., *L. royleana* Benth. in Wall, *L. canescens* (L.) Fischer & C.A.Mey., and *L. peltata* (L.) Fisch. & C.A.Mey. (Rechinger, 1982). It is found in different regions of European and Middle East countries, especially Iran (Zargari 1980; Naghibi et al., 2005). *Lallemantia* is an annual or perennial herb, a dwarf shrub (Anonymans, 2003), and is characterized by simple, ovate to round or sometimes linear, aristae-toothed bracteole, oblong, trigonous, smooth, and mucilaginous nettled leaves (Harley et al., 2004). It is a good source of fiber, oil, and protein and has medicinal properties (Naghibi et al., 2005). This natural herb is used for the treatment of reflux of stomach (Anonymans, 2012), arthritis, joint pain, rheumatism, osteoarthritis, and abscesses (Mahmood et al., 2013). Balangu seeds are used in a wide range of traditional and industrial products such as a beverage namely *Tokhme Sharbati* and a bread in Iran and Turkey (Mahmood et al., 2013). The seed contains up to 30 % of a drying oil used for lighting, as a varnish, in paints as a lubricant (Usher, 1994), as a wood preservative, as an ingredient in oil-based paints, in furniture polishes, in printing inks, and in soaps. The oil could also be used for oil-foods and as a tanning agent. It is also used in the manufacture of linoleum (Anonymans, 2003). Sustainability and the overall management of water resources have been the greatest challenges of the century. World population has passed the six billion mark. Based on the proportion of young people in developing countries, the requirement for water will continue to increase significantly during the next few decades. This places an enormous demand on the world's limited irrigation water supply; thus, a precise knowledge of crop water requirements has become an essential prerequisite for the efficient use of water supplies (Reddy, 1999). Plants exposed to drought or drought stress have evolved a series of morphological and physiological adaptations which gives them tolerance to these stresses (Kumar et al., 2005). The degree of adaptation to the decrease in water potential caused by drought may vary considerably between species (Savé et al., 1995) and also within a species (Parker & Pallardy, 1985). Drought stress decreases the rate of photosynthesis (Kawamitsu et al., 2000; Rivero et al., 2007). Plants grown under drought conditions have a lower stomatal conductance in order to conserve water. Consequently, CO₂ fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for plant growth and yield. Diffusive resistance of the stomata to CO₂ entry is probably the main factor limiting photosynthesis in

drought (Boyer, 1970). Certainly, under mild or moderate drought stress, stomatal closure causing reduced internal leaf CO₂ concentration is the major reason for reduced rates of leaf photosynthesis (Chaves, 1991; Cornic, 2000; Flexas et al., 2004; Romero-Romero et al., 2018). Another plant response to drought stress is to change the content of photosynthetic pigments that play important roles in light harvesting (Farooq et al., 2009; Ommen et al., 1999). Severe drought stress also inhibits plant photosynthesis by causing changes in chlorophyll content, by affecting chlorophylls components, and by damaging the photosynthetic apparatus (Iturbe-Ormaetxe et al., 1998). Drought stress causes a large decline in the chlorophyll *a* content, the chlorophyll *b* content, and the total chlorophyll (Manivannan et al., 2007). The decrease in chlorophyll under drought stress is mainly the result of damage to chloroplasts caused by reactive oxygen species (Ramirez et al., 2014). The effects of drought stress on chlorophyll and carotenoids content have been investigated some crops including cotton (Mssacci et al., 2008) and *Catharanthus roseus* (L.) G. Don (Jaleel et al., 2008). Water deficit reduces leaf area and the number of leaves per plant and leads to a reduction in crop growth. Loss of leaf area, which could result from the reduced size of younger leaves and the inhibition of the expansion of developing foliage, is also considered an adaptation mechanism to drought (Gebeyehu, 2006). In bean, reduced leaf area causes a decrease in canopy temperatures and a cooling of the plant growth environment (Ghanbari et al., 2013). Wentworth et al. (2006) determined the photosynthetic characteristics of two contrasting varieties of the common bean (*Phaseolus vulgaris* L.) under drought stress. Both varieties showed reduced chlorophyll content on a leaf area basis, a decrease in leaf area, and an increase in leaf thickness. Numerous biochemical changes occur in response to drought stress. Changes in mucilage (Rahimi et al., 2011) and protein accumulation and synthesis have been observed in many plants species as a result of plant exposure to drought stress during growth (Chen & Tabaeizadeh, 1992; Salehi et al., 2016; Omid et al., 2018). The study of water use efficiency becomes particularly important in situations where growth is affected by limited water availability (Anyia & Herzog, 2004). Maximum water use efficiency is achieved at the limit between diffusional and metabolic limitations to photosynthesis (Flexas et al., 2004). However, there is still a lack of information about the morpho-physiological behavior of different *Lallemantia* species under conditions of limited water availability. Therefore, the main objective of this study was to determine the response of different species of *Lallemantia* to drought stress by evaluating their productivity and selected morphological, physiological, and biochemical parameters.

2 MATERIALS AND METHODS

2.1 CROP PRODUCTION, TREATMENTS AND EXPERIMENTAL DESIGN

The field experiment was conducted at the Research Farm of the Agricultural College of Shahed University, Tehran (Fig 1), during the years 2012-2014. Prior to preparing the plots, five points were sampled at a depth of 30 cm, and soil analyses were conducted. The soil type was loam-silty, the percentage of organic carbon was 0.77, the N content was 0.08%, the exchangeable K and available P content were 382 mg kg⁻¹ and 22.3 mg kg⁻¹, respectively, and the pH was about 8. The climate was arid to semiarid with an average rainfall of 216 mm per year. Some physical properties of the soil layer at a depth of 30 cm are given in Table 1.

In this study, the *Lallemantia* species were used as the crop material. After field preparations, the experimental area was divided into 36 plots measuring 3 × 1.5 m in size. Between contiguous plots a distance of 1 m in each replication and 1.5 m between replications was maintained. The seeds were sown on the 14th of March 2012 at a row spacing of 25 cm and plant spacing of 5 cm in the rows. Cultivation practices, such as weeding, thinning, fertilizing, etc., were applied according

to crop needs. The field experiment was designed as a split plot factorial in a complete randomized block design with three replications. The main factor was irrigation treatments, scheduled based on depletion of ASW over 30 cm soil depth including 40 %, 60 %, and 100 % depletion of ASW (abbreviated to I₄₀, I₆₀, and I₁₀₀). The second factor was two species of *Lallemantia* *L. royleana* (S₁), *L. iberica* (S₂). All plots received the same amount of water from germination to flowering. The irrigation treatments were applied at the onset of flowering. The percentage depletion of water (ASW) in the 0-30 cm layer of soil was estimated by measuring the soil water content gravimetrically using Eq. (1) (Martin et al., 1990):

$$\text{Eq. (1)} \quad D (\%) = 100 \times \frac{F_C - \theta}{F_C - W_p}$$

Where D is depletion, F_C is the soil moisture at field capacity, θ is the soil moisture, and W_p is the soil moisture at wilting point. The amount of water applied based on each treatment was calculated using Eq. (2) (Rostamza et al., 2011):

$$\text{Eq. (2)} \quad I_n = \frac{(F_C - \theta) \times D \times A}{100}$$



Figure 1: Geographical location of experiment

Table 1: Some physical properties of 0-30 cm layer of soil

Particle size distribution (%)			Soil type	Bulk density (g cm ⁻³)	Field capacity (% gravimetrically)	Wilting point (% gravimetrically)
Clay	Silt	Sand				
18	24	58	Loam-silty	1.8	21.2	11

Where I_n is the volume of irrigation water, D is the effective rooting depth, and A is the plot surface area. The surface area of each plot measured 4.5 m^2 . Each plot was watered individually through the furrows. Before applying irrigation treatments, the amount of water required was determined by monitoring changes in soil water gravimetrically. Every 2 days a soil sample was taken from a depth of 0-30 cm, dried in an oven at $105 \text{ }^\circ\text{C}$ for 24 h, and then the soil moisture was measured.

2.2 SAMPLING AND ANALYZING

2.2.1 Water use efficiency (WUE)

WUE is a quantitative measurement of how much biomass or yield is produced over a growing season, normalized with the amount of water used up in the process (Anonymous, 1998). Besides absolute yield, water use efficiency is an important agronomic factor, especially in agricultural irrigation systems and in climate areas where a limited amount of water from the rainy season has to last for the whole growth period as no further rainfall can be expected (Anonymous, 1998). In this experiment the WUE was calculated as the economical yield per unit of evapotranspiration of the crop.

($\text{WUE} = Y \text{ ET}^{-1}$). ET was calculated using Eq. (4) (Garrity et al., 1982):

$$\text{Eq. (4)} \quad \text{ET} = P + I - R - D_p \pm \Delta S$$

Where ET is crop water consumption (mm), P is rainfall (mm), I is irrigation water (mm), R is surface runoff (mm), D_p is deep percolation (mm), and ΔS is soil water content variation in crop root depth (mm). Therefore, total ET values were calculated using a summation of all ET during the growing season. In this study, D_p and R_i in Eq. (4) were assumed to be negligible. Since the slope of each plot was near zero and the amount of irrigation water was only enough to reach field capacity, it was also assumed that there was no deep percolation.

2.2.2 Chlorophyll content

Chlorophyll content was measured in each irrigation treatment, I_{40} , I_{60} , and I_{100} , and for every *Lallemantia* species. Measurements were performed on the appropriate method of Arnon (1994) with a modified formula (Porra, 2002). Chl was extracted by grinding 0.1 g of leaf material in 80 % acetone. The extract was centrifuged at

3000 rpm for 5 min, the supernatant was collected, and the process was repeated until the pellet became white or yellow in color. The supernatants were pooled, and absorption was read by spectrophotometer (Model Spectronic 20; Milton Roy Co., USA) at wavelengths of 645 nm, 663.6 nm, and 664.4 nm. Eventually the optical density was noted for the estimated chlorophyll content (Saraswathi & Paliwal, 2011) using Eq. (4).

Eq. (4):

$$\text{Chlorophyll a } (\mu\text{g ml}^{-1}) = 12.25 (A_{663.6}) - 2.55 (A_{646.6})$$

$$\text{Chlorophyll b } (\mu\text{g ml}^{-1}) = 20.31 (A_{646.6}) - 4.91 (A_{663.6})$$

$$\text{Total chl } (\mu\text{g ml}^{-1}) = 17.76 (A_{646.6}) + 7.34 (A_{663.6})$$

2.2.3 Leaf area index (LAI)

Leaf area index is defined as the one sided leaf area of a plant per the ground area covered by canopy (Burton et al., 1991; Cutini et al., 1998). The area of each leaf was measured per 2.0 m^2 of every plot with a leaf area meter (AM200, Bioscientific Co.). To calculate the leaf area, the number of leaves was multiplied by the average leaf area.

2.2.4 Leaf stomata variation

Optical microscopy was used to assess the response of *Lallemantia* species leaf stomata to irrigation regimes. A very thin layer of the abaxial epidermis was taken. After the chlorophyll was removed with bleach and distilled water, lam and lamella samples were prepared (Akbarinia et al., 2012). Then the percentage of closed and open leaf stomata was calculated per 1.0 mm^2 .

2.2.5 Root length variation

In June 2012, at the end of the experiment, plant roots were extracted, the attached soil was removed by washing, and the root length was determined using the line intersection method (Tennant, 1975) from which root length could be calculated for soil layer samples from a depth of 30 cm.

2.2.6 Yield production

In this experiment, plants were harvested 3 months after planting, right after the physiological maturity of *Lallemantia* to avoid losing plant material. The effects of

the drought treatments on seed yield were assessed. Samples were collected from 2.0 m² of plot.

2.2.7 Seed quality

Seed chemical composition was determined as protein percentage by determining the nitrogen content using the Micro kjeldahl method (Cohen, 1910). The nitrogen percentage was multiplied by 6.25 to calculate the percentage of protein in the seeds. Seed mucilage was measured for every treatment using Kalnyasundaram's method (1982). Measures of protein yield and mucilage yield were obtained by multiplying the percentage of protein and mucilage by seed yield.

2.2.8 Data analysis

Statistical software was used for data analysis, correlations, and all mean comparisons (Duncan). A p-value of 0.01 was considered statistically significant. All graphs were drawn using Microsoft Office Excel

3 RESULTS

3.1 WEATHER CONDITIONS AND IRRIGATION

The average monthly maximum air temperature varied between 11 °C and 38.7 °C, and the average temperature exceeded 35 °C in June. The lowest average

monthly minimum temperature of 2.2 °C was observed in February (Fig. 2). The number of irrigation treatments and total water volume applied during the experiment are shown in Table 2. The interaction between irrigation treatments and species were observed on the LAI of the *Lallemantia* species (Fig 3).

3.2 THE EFFECT OF WATER STRESS ON GROWTH COMPONENTS OF LALLEMANTIA SPECIES

3.2.1. Leaf area index (LAI)

The variance analysis indicated that LAI of the *Lallemantia* species was significantly affected ($P < 0.01$) by the interaction effect of irrigation regimes and species (Table 3). LAI was directly affected by the amount of water applied. The highest values were seen in I₄₀, and they decreased as drought stress increased (Fig. 2). Under severe drought stress conditions (I₁₀₀), the LAI was the least in both species. There was no significant difference in the LAI of *L. royleana* in any irrigation system, however in *L. iberica* the LAI was significantly reduced as drought stress increased. As the water depletion increased in I₆₀ and I₁₀₀, the LAI decreased 24.6 % and 49.62 %, respectively compared to I₄₀ in *L. iberica* (Fig. 3). The mean comparison of LAI in Fig. 2 showed that in all species, the leaf area index decreased during plant growth as the intensity of drought stress increased. As the water depletion increased in I₆₀ and I₁₀₀, leaf area index decreased. Among drought adaptation strategies, the minimization

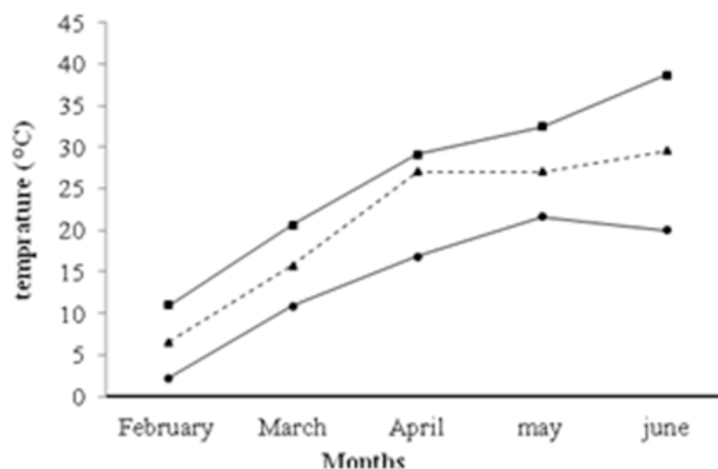


Figure 2: Average monthly maximum (—■—), minimum (—●—) and mean (—△—) temperatures (°C) for the experimental site in 2012-2014..

Table 2: Number of irrigations and amount of water applied per irrigation treatments to *Lallemantia* species plots after starting water regimes

Treatments	Number of irrigation	Total amount of applied water (mm)
I40 S1	9	237
I40 S2	9	238
Mean		235.75
I60 S1	5	200
I60 S2	5	199
Mean		199.25
I100 S1	2	117
I100 S2	2	115
Mean		113.5

Table 3: Analysis of variance of chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll (Ch T), percentage of closed stomata (CS), percentage open stomata (OS), leaf area index (LAI), root length (RL), water use efficiency (WUE), yield (Y) and thousand seed mass (TSM)

S.O.V	df	Mean square	Chl a	Chl b	Chl T	%CS	%OS	LAI	RL	WUE	Y	TSD
Block	2	2.5×10^{-7} n.s.	7.77×10^{-7} n.s.	9.11×10^{-7} n.s.	41.49 n.s.	41.45 n.s.	0.105 n.s.	0.118 n.s.	0.234 n.s.	1481.6 n.s.	7×10^{-5} n.s.	
Irrigation	2	3.7×10^{-6} **	2.40×10^{-6} n.s.	1.82×10^{-6} n.s.	7936.59 **	7936.92 **	5.260 **	0.806 n.s.	0.583 *	29815.5 *	312×10^{-5} **	
<i>Lallemantia</i> species	1	2.2×10^{-6} **	1.84×10^{-6}	7.98×10^{-6}	210.73 n.s.	210.64 n.s.	6.890 **	0.0001 n.s.	0.260 n.s.	909.03 n.s.	45×10^{-6} n.s.	
Irrigation \times species	2	6.25×10^{-7} n.s.	5.54×10^{-7} n.s.	4.34×10^{-7} n.s.	344.13 n.s.	344.08 n.s.	2.041 **	0.282 n.s.	0.389 *	6642.9 n.s.	17×10^{-4} n.s.	
Error	18	1.8×10^{-7}	1.42×10^{-6}	1.43×10^{-6}	116.95	116.97	0.150	1.186 n.s.	0.176	2131.69	14×10^{-6} n.s.	
Total	35											

*, **: significant at 5 % and 1 % probability levels, respectively, and n.s: non-significant.

of water loss can be achieved through lowering either leaf area or stomatal conductance or by reducing the energy load of the plant (Rauf & Sadaqat, 2008). It is noteworthy that yield was not significantly different between S_1 and S_2 , but as drought intensity increased, LAI decreased in S_1 significantly. Therefore, it is concluded that S_1 is more

sensitive to soil water depletion than S_2 . Pandey et al. (2000) found that reducing LAI to decrease transpiration and deepening the root system to increase water extraction are adaptive strategies in maize plants under water stress. Hence, dry matter production decreases with a decrease in the leaf area index. Similar results were also

Table 4: Analysis variance of seed quality of *Lallemantia* species under irrigation treatments

S.O.V	df	Mean square	Protein %	Protein yield	Mucilage %	Mucilage yield
Block	2	1.30 n.s.	2.40 n.s.	0.068 n.s.	5.65 n.s.	
Irrigation	2	2.24 n.s.	39.29 *	8.08 **	60.01 *	
<i>Lallemantia</i> species	1	61.09 **	30.28 **	54.02 **	16.78 n.s.	
Irrigation species	2	8.87 *	8.90 n.s.	0.772 n.s.	20.32 n.s.	
Error	18	1.55	2.70	1.217	9.82	
Total	35					

*, **: significant at 5 % and 1 % probability levels, respectively, and n.s: non-significant

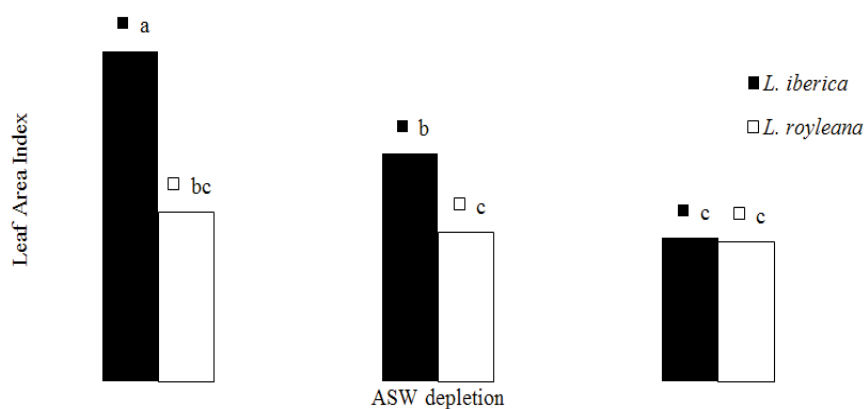


Figure 3: The interaction of water stress and *Lallemantia* sp on leaf area index (LAI). Different letters indicate significant difference (p 0.01) according to Duncan test.

reported by Tashiro and Wardlaw (1990). Stagnari et al. (2018) reported that the leaf area of radish reduced when the plants were exposed to drought stress. Rostamza et al. (2011) demonstrated a positive relationship between drought intensity and the reduction in LAI and dry matter from 7 % to 45.5 %. This can be associated with the fact that plants exposed to water stress served the photosynthetic sources to stay green and produce more dry matter. Furthermore, Hopkins et al. (2008) stated that leaf size could increase with increasing air temperatures. Large leaves have thicker boundary layers of air around their surfaces which insulate them and decrease water loss through transpiration.

3.2.2 Root Length

Results given in Table 3 showed no significant effect in root length among all irrigation regimes and *Lallemantia* species. Drought stress decreased root length, but not significantly. The same result was reported in strawberry cultivars by Klamkowski and Tender (2008) who demonstrated that cultivars 'Elsanta' and 'Salut' were not affected by irrigation regimes. Generally, growth inhibition in response to reduced water availability was higher in the above-ground portions of the plants than in the root systems. A deeper, more extensive root system enables plants to increase water uptake and survive during drought stress (Klamkowski & Tender, 2008).

Data of Chlorophyll a, Chlorophyll b, Total Chlorophyll, open and closed stomata, leaf area index, root length, water use efficiency, grain yield and grain qual-

Table 5: The mean chlorophyll a (Chl a), chlorophyll b (Chl b), total Chlorophyll (Chl T), closed stomata (CS) open stomata percentage (OS) per mm², leaf area index (LAI), root length (RL) water use efficiency (WUE), yield (Y), thousand seed weight, percentage of grain protein, grain protein yield, percentage of grain mucilage and grain mucilage yield of *Lallemantia* species affected by different irrigation regimes

Irrigation level	Chl b		Chl T (mg g ⁻¹)	CS	OS	LAI	RL (cm)	WUE (kg m ⁻³)	Y (kg ha ⁻¹)	TSW	protein	Protein yield	Mucilage	Mucilage yield
	Chl a (mg g ⁻¹)	(mg g ⁻¹)												
I40	0.0087 a	0.0098 a	0.0175 a	24.11 b	75.88 a	2.68 a	6.02 a	1.18 ab	208.37 a	0.888 a	21.57 a	7.27 a	5.46 c	11.22 a
I60	0.0082 a	0.0117 a	0.0199 a	64.61 a	35.38 b	2.02 ab	5.50 a	0.79 b	127.01 b	0.866 b	20.75 b	3.96 b	6.30 b	6.75 b
I100	0.0070 b	0.0107 a	0.0180 a	71.82 a	28.17 b	1.35 b	5.77 a	1.51 a	138.12 b	0.856 c	20.92 ab	4.34 b	7.10 a	8.95 ab
<i>Lallemantia</i> species														
S1	0.0079 b	0.011 a	0.0190 a	55.93 a	44.89 a	2.45 a	5.76 a	1.24 a	167.06 a	0.95 a	22.38 a	6.11 a	5.06 b	8.29 a
S2	0.0084 a	0.009 a	0.0180 a	51.10 a	48.99 b	1.58 b	5.76 a	1.07 a	135.28 a	0.78 b	19.78 b	4.27 b	7.51 a	9.66 a

ity characteristics were averaged for both *Lallemantia* species (*L. iberica*) S₁, (*L. royleana*) S₂. Values within the column followed by the different letters are significantly different according to the Duncan test at 0.01 probability level.

3.2.3 Chlorophyll content

Results showed that the effects of irrigation and species were not significant on chlorophyll *a* content (Table 3). Drought stress also inhibited the photosynthesis of plants by affecting chlorophyll content and damage to the

photosynthetic apparatus (Mafakheri et al., 2010). In this study, increasing the intensity of drought stress resulted in decreased chlorophyll *a* content. S₁ (*L. iberica*) showed the significant, lower chlorophyll *a* content across all water stress treatments. The results of this study are in agreement with those of Nyachiro et al. (2001), who described a significant decrease in chlorophyll *a* caused by water deficit in six *Triticum aestivum* L. cultivars. The effect of species on chlorophyll *b* and total chlorophyll were not significant. Decreased or unchanged chlorophyll levels during drought stress and dependent upon the duration and severity of drought had been reported in other species (Kpyoarissis et al., 1995). The content of total chlo-

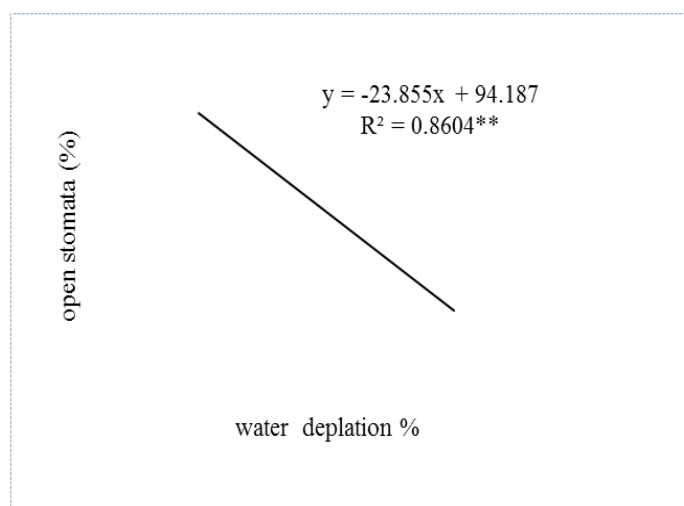


Figure 4: Linear regression between percentage of soil water depletion and percentage of open stomata in the fully expanded topmost leaf of the main shoot. The regression coefficient is significant at $p < 0.01$.

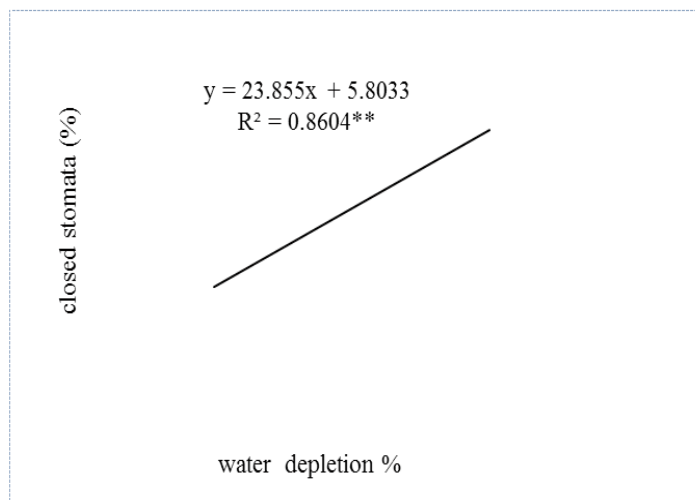


Figure 5: Linear regression between percentage of soil water depletion and percentage of closure stomata in the fully expanded topmost leaf of the main shoot. The regression coefficient is significant at $p < 0.01$.

rophyll on leaf dry mass increased with an increase in the intensity of drought stress, but not significantly. An increase of total chlorophyll under drought stress implies an enhanced capacity for light harvesting. Since the production of a reactive oxygen species is mainly driven by excess energy absorption in the photosynthetic apparatus, this might be avoided by degrading the absorbing pigments (Herbinger et al., 2002).

3.2.4 Stomata responses to drought stress

Variance analysis revealed that irrigation regimes had significant effects on the percentage of closed and open stomata ($p < 0.01$) (Table 3). There was a linear regression ($R^2 = 0.86^{**}$) between the percentage of soil water depletion and the percentage of closed and open stomata. (As drought stress increased, closed stomata increased, reaching the highest value in I_{100} (Fig 5). Open stomata showed a 75.8 % reduction in I_{100} compared to the well irrigation treatment (I_{40}) (Fig 2). Water availability is a limiting factor for a wide range of physiological processes in plants. One of the first responses of plants to drought is stomatal closure, which restricts gas exchange between the inside of the leaf and the atmosphere. Therefore, this is the main means of regulating water relations and carbon assimilation in plants (Hetherington & Woodward, 2003). Stomatal closure protects plants against excessive water loss, but also restricts the diffusion of CO_2 into the photosynthetic parenchyma (Chaves et al., 2003). S_2 not only had more open stomata but also showed less closed stomata than S_1 , indicating a high ability of S_2 to retain water in its tissues.

3.3. WATER USE EFFICIENCY OF *LALLEMANTIA* SPECIES

Water use efficiency is defined as the amount of dry matter production (grain) per unit of water consumed (evapotranspiration). The number of irrigation treatments and the total water volume applied during the experiment are shown in Table 2. The effect of irrigation regimes was significant ($p < 0.05$) on WUE (Table 3). The highest WUE was observed in I_{100} , and the lowest was reported for I_{60} (Table 5). WUE decreased 33.05 % as drought stress intensity increased up to 60 % ASW. As water depletion increased to more than 60 %, WUE increased 21.85 % compared with I_{40} , which was not significant (Table 5). The interaction between drought stress, *Lallemantia* species was significant (Table 3). The highest WUE by 1.96 kg m^{-3} was obtained in I_{100} , *L. royleana*; the lowest WUE by 0.429 kg m^{-3} was reported for I_{60} , *L. royleana* (Fig 6). In the present study, WUE varied significantly depending on water availability. The results shown in Table 5 revealed that the highest water use efficiency was obtained when irrigation was scheduled on minimum irrigation (I_{100}), while more soil water depletion of (I_{60} and I_{100}) improved WUE. The interaction between irrigation regimes showed that the behavior of *Lallemantia* species toward irrigation regimes was the same. The interaction of drought stress and *Lallemantia* species was significant. Our results are contrary to those reported in strawberry cultivars by Klamkowski and Tender (2008), who demonstrated that in drought stress, water use efficiency of the 'Salut' cultivar decreased. Our results were in agreement with the findings of Rostamza et al. (2011), Zegada-Lizarazu and Ijima (2005), and Nagaz et al.

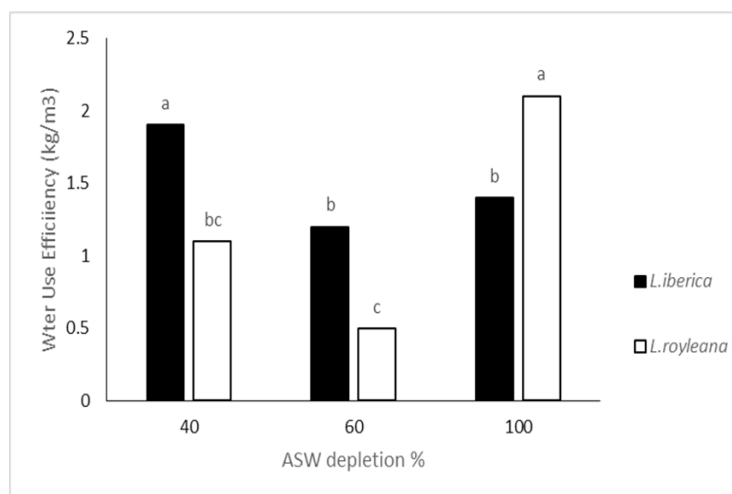


Figure 6: The interaction of drought stress and *Lallemantia* species on Water Use Efficiency (WUE). Different letters indicate significant difference ($p < 0.05$) according to Duncan test.

(2009) who reported that WUE increased under drought stress conditions. Chaves et al. (2003) stated that most plants tend to show an increase in water use efficiency under conditions of mild or moderate water deficiency. This increase results from the non-linear relationship between stomata conductance and carbon assimilation. Water loss is restricted earlier and more intensely than the inhibition of photosynthesis. High WUE reflects an ability to maintain photosynthetic capacity under conditions of water deficiency and a higher resistance to drought (Bota et al., 2001).

3.4. THE WATER DEPLETION EFFECTS ON YIELD OF *LALLEMANTIA* SPECIES

The effect of irrigation was significant ($p < 0.05$) on yield (Table 3). The yield response to drought stress is given in Fig 6. The yield of I_{40} was significantly higher than those of I_{60} and I_{100} , but there was no difference between the yields of I_{60} and I_{100} (Table 5). As water depletion increased to 60 % and 100 %, yield decreased 39.04 % and 33.71 %, respectively, compared with I_{40} (Table 5). Although S_1 had more yield than S_2 , the amount was not significant. The interactions between drought stress and species were significant (Table 3). The highest yield, 297.22 kg ha⁻¹, was obtained in I_{40} , *L.iberica*; the lowest grain yield, 63.40 kg ha⁻¹, was related to I_{60} , *L. royleana* (Fig. 7).

Grain yield is the main objective of crop production. Grain yield of *Lallemantia* was significantly affected by drought stress. Mean comparisons showed that the maximum grain yield (208.37 kg ha⁻¹) was obtained in I_{40}

and the minimum was obtained when 100 % of AWS was evacuated. Treatments (I_{60}) and (I_{100}) gave similar results; however, there was no significant difference between these treatments. These results are similar with total dry matter and leaf area index. According to the results, even though grain yield was not significantly different in S_1 and S_2 , S_1 showed more grain yield compared with S_2 . This might be related to a correlation between grain yield with total dry matter and leaf area index. Weber et al. (1996) reported that both leaf area index and total dry matter were poor predictors of grain yield. Winter and Ohlrogge (1993) suggested that grain yield in each treatment increased when leaf area index and total dry matter increased. In this study, grain yield increased when leaf area index increased.

3.4.1 Thousand seed mass

Drought stress had a highly significant ($p < 0.01$) effect on 1000-seed mass (Table 3). The results of means comparisons indicated that the water stress treatments significantly decreased 1000-seed mass (Table 5). The results also demonstrated that there was significant difference between *Lallemantia* species. *L. iberica* showed the highest 1000-seed mass compared with *L. royleana*. Increasing severity of drought stress reduced 1000-seed mass. In fact drought stress reduced leaf area index, stomatal conductance, photosynthetic pigments, and photosynthesis that affected the transferring grain dry matter and 1000-seed mass.

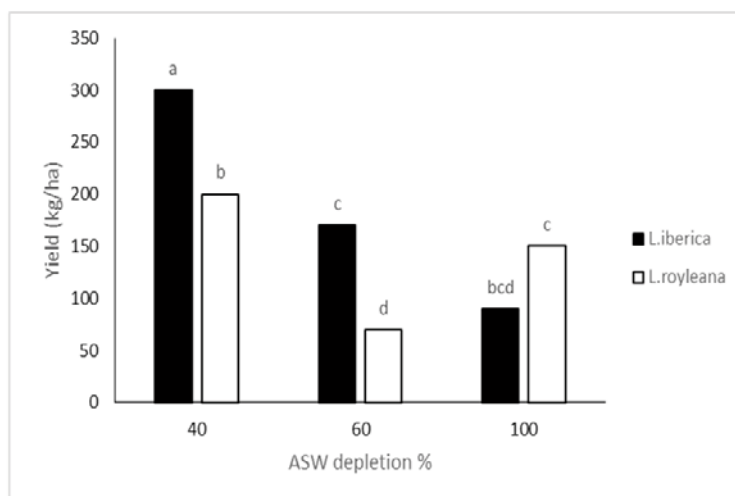


Figure 7: The interaction of drought stress and *Lallemantia* species on grain yield. Different letters indicate significant difference ($p < 0.05$) according to Duncan test.

3.5 THE WATER DEPLETION EFFECTS ON SEED QUALITY OF SPECIES

3.5.1 Mucilage

Data indicated the percentage of seed mucilage was affected by the irrigation treatments (Table 4). As drought intensity increased, the percentage of seed mucilage decreased (Table 5). The highest percentage of mucilage was related to I_{100} , and the lowest was reported for I_{40} . As the intensity of available soil water depletion increased to 60 % and 100 %, the mucilage percentage increased 13.33 % and 30.3 %, respectively. There was a significant difference in the percentage of seed mucilage between *Lallemantia* species. *L. royleana* with 7.51 % showed the highest percentage of seed mucilage compared with *L. iberica*. Mucilage yield was significantly affected by irrigation treatments. The highest and the lowest mucilage yields (11.22 kg ha^{-1} and $(6.75 \text{ kg ha}^{-1})$ were related to I_{40} and I_{60} , respectively. Although an increase in the severity of drought stress caused the seed mucilage yield to decline, there was no significant difference between the values of I_{40} and I_{100} . It seems that increased seed coated mucilage in water deficit conditions occurs because of the genetic and morphological adaptation of plants to protect fertile new embryo in severe drought stress. Our results are in agreement with the findings of Rahimi et al. (2011) and contrary to those of Mousavi-Nik (2012). Data shown in Table (5) clearly indicates there were significant differences between drought stress treatments in seed mucilage yield. The decreasing trend of seed mucilage yield as the depletion of available soil water increases

may be attributed to the fact that plants in I_{60} and I_{100} had fewer seeds/plant (grain yield) than those of I_{40} . In fact, the reduction of grain mucilage yield may be due to the accumulation of salt minerals around the plant roots in drought stress conditions, which impairs the absorption and transport of nutrients to the shoots and ultimately reduces the synthetics of active substance in plants.

3.5.2 Protein

Results showed the percentage of seed protein was affected by different irrigation regimes (Table 4). Increasing the intensity of available soil water depletion resulted in decreased seed protein percentage. The highest and the lowest protein contents were obtained in I_{40} and I_{60} , respectively (Table 5). Increasing the intensity of available soil water depletion up to 60 % resulted in a significantly decreased protein content (3.80 %). Increasing the severity of available soil water depletion to 100 % resulted in a decreased seed protein content (3.01 %), but the decrease was not significant (Table 5). The interaction effects of drought stress and *Lallemantia* species were significant on protein content. Increasing the severity of drought stress resulted in a significant decrease in the protein content of *L. iberica*, however the decrease was not significant in *L. royleana*. Protein yield was affected by the irrigation regimes (Table 4). The effect of interaction between drought stress and *Lallemantia* species was significant (Fig 8). The highest protein yield was obtained in I_{100} , *L. royleana*, and the lowest was reported in I_{60} , *L. royleana*. Increasing the intensity of available soil water depletion up to 60 % resulted in a decrease in protein yield in both

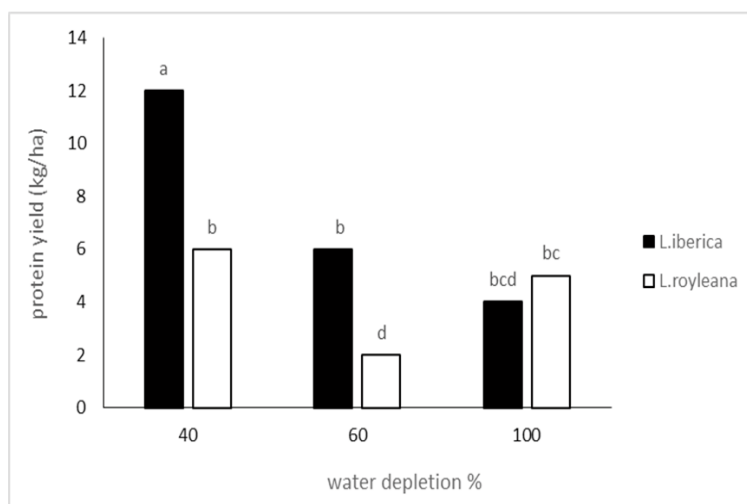


Figure 8: The interaction of drought stress and *Lallemantia* species on protein yield. Different letters indicate significant difference ($p < 0.05$) according to Duncan test.

species, but as water depletion increased to more than 60 %, protein yield increased. Drought stress is one of the most important factors that influence and decrease seed protein content (Daneshian et al., 2002). According to the results of our study, increasing the severity of drought stress resulted in decreased seed protein percentage, which is in agreement with the results of Johnson et al. (2002). One of the factors reducing seed protein content in plants exposed to drought stress may be severe drop of the photosynthesis productions and subsequent reductions in precursor protein production and may be attributed to a decrease in protein synthesis (Mohamadkhani & Haydari, 2008). In fact drought stress reduces protein content by increasing the activity of protein degrading enzymes and decreasing photosynthesis. The highest protein yield of I_{100} was related to the increased adaption of plants to drought conditions from the beginning of growth compared to those reported for I_{60} and I_{40} . Our results were consistent with those of Musallam et al. (2004) and contrary to those obtained by Alghamdi (2003). The allocation of photosynthetic substrates was expected to be high among plants under I_{40} compared with I_{60} . The seeds of these plants were also expected to have less protein, but a higher yield.

4 CONCLUSION

The present study was designed to determine the effect of soil moisture content on ecophysiological responses of *Lallemantia* species. This study has shown that *L. royleana* has tolerance to water shortage in soil. Despite drought reduced leaf area index, stomatal conductance, and photosynthetic pigments, which ultimately reduces grain yield, water use efficiency significantly increased with the increment in severity of drought stress especially in *L. royleana*. The evidence from this study suggests that *Lallemantia* is an efficient plant in low input systems of water supply. An implication of this is the possibility for producer to use *Lallemantia* as an important medicinal and industrial plant to grow in low input systems in which water scarcity is the most limiting growth factor. This research extended our knowledge about *Lallemantia* species responses specially water use efficiency under water shortage condition in soil. This is the first study reporting water use efficiency of two species of *Lallemantia*. However these findings are limited by the use of one seed lot of each species. It is recommended that further research be undertaken with 3 or more seed lots.

5 REFERENCES

Acuqaah, G. (2002). *Principle of Crop Production, Theory, Techniques and Technology*. Prentice-Hall of India, Co. Pvt. Ltd.

- Akbarinia, M., Zarafshan, M., Sattarian, A., Sustani, F., Ghanbari, E., & Chaplugh Paridari, I. (2012). Morphological variations in stomata, epidermal cells and trichome of sweet chestnut (*Castanea sativa* Mill.) in Caspian ecosystem. *Taxonomy and Biosystematics*, 3(7), 23-32.
- Alghamdi, S.S. (2003). Effect of various water regimes on productivity of some faba varieties in central region of Saudi Arabia. *Agricultural Research Center, King Saud University*, 124, 5-22.
- Anonymous, (1998). Retrieved from www.lemnaTec.com.
- Anonymous, (2003). Retrieved from <http://www.inaro.de/Deutsch/KULTURPF/Drachenkopf/Anbaute.html>
- Anonymous, (2012). Retrieved from <http://dehkade.frood.blogfa.Com>.
- Anyia, A.O., & Herzog, H. (2004). Water Use Efficiency, Leaf gas Exchange of Cowpeas under Mid-season Drought. *European Journal Agronomy*, 20, 327-339. [https://doi.org/10.1016/S1161-0301\(03\)00038-8](https://doi.org/10.1016/S1161-0301(03)00038-8)
- Arnon, D.L. (1994). Copper enzymes in isolated chloroplasts, Polyphenol oxidase in *Beta vulgaris*. *Plant Physiology*, 24, 1-15. <https://doi.org/10.1104/pp.24.1.1>
- Bota, J., Flexas, J., & Medrano, H. (2001). Genetic variability of photosynthesis and water use in Balearic grapevine cultivars. *Annual Applied Biology*, 138, 353-361. <https://doi.org/10.1111/j.1744-7348.2001.tb00120.x>
- Boyer, J.S. (1970). Leaf enlargement and metabolic rates in corn, soybean, and sunflower at various leaf water potentials. *Plant Physiology*, 46, 233-235. <https://doi.org/10.1104/pp.46.2.233>
- Chaves, M.M. (1991). Effects of water deficits on carbon assimilation. *Journal of Experimental Botany*, 42, 1-16. 353-361 <https://doi.org/10.1093/jxb/42.1.1>
- Chen, R.D., & Tabaeizadeh, Z. (1992). Alteration of gene expression in tomato plants (*Lycopersicon esculentum*) by drought and salt stress. *Genome*, 35, 385-391. <https://doi.org/10.1139/g92-058>
- Cornic, G. (2000). Drought stress inhibits photosynthesis by decreasing stomatal aperture – not by affecting ATP synthesis. *Trends Plant Science*, 5, 187-188. [https://doi.org/10.1016/S1360-1385\(00\)01625-3](https://doi.org/10.1016/S1360-1385(00)01625-3)
- Daneshian, J., & Jonubi, P. (2002). Effect of drought stress and calcium in soybean characteristics. *Agronomy Science*, 1, 95-108.
- Escalona, J.M., Flexas, J., & Medrano, H. (1999). Stomatal and non-stomata limitations of photosynthesis under water stress in field-grown grapevines. *Australian journal of plant physiology*, 26, 421-433. <https://doi.org/10.1071/PP99019>
- Farooq, M., Wahid, A., Kobayashin., Fujita, D., & Basra, S.M.A. (2009). Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development*, 29, 153-188. <https://doi.org/10.1051/agro:2008021>
- Flexas, J., Bota, J., Loreto, F., Cornic, G., & Sharkey, T.D. (2004). Diffusive and metabolic limitations to photosynthesis under drought and salinity in C3 plants. *Plant Biology*, 6, 1-11. <https://doi.org/10.1055/s-2004-820867>
- Garrity, D.P., Watts, D.G., Sullivan, C.Y., & Gilley, J.R. (1982). Moisture deficits and grain-sorghum performance evapotranspiration yield relationships. *Agronomy Journal*, 74,

- 815-820. <https://doi.org/10.2134/agronj1982.00021962007400050011x>
- Gebeyehu S, (2006). *PhD Thesis*, Justus-Liebig-Universitat (Giessen, Germany).
- Ghanbari, A.K., Shakiba, M.R., Toorchi, M., & Ghoukan, R. (2013). Morpho-physiological responses of common bean leaf to water deficit stress. *European Journal of Experimental Biology*, 3(1), 487-492. Retrieved from www.pelagiaresearchlibrary.com
- Gupta, N. K., & Gupta, S. (2005). *Pant Physiology*. Oxford and IBH Publishing. Herbingen K., Tausz, M., Wonisch, A., Soja, G., Sorger A., & Grill, D. (2002). Complex interactive effects of drought and ozone stress on the antioxidant defense systems of two wheat cultivars. *Plant Physiology and Biochemistry*, 40, 691-696. [https://doi.org/10.1016/S0981-9428\(02\)01410-9](https://doi.org/10.1016/S0981-9428(02)01410-9)
- Harley, A.M., Atkins, S., Budantsev A.L., Cantino, P.D., Conn, B.J., Grayer, R., Harley, M.M., DE Kok R., Krestovskaja, T., Morals, R., Paton, A.J., Ryding, O., & Upson, F. (2004). Lamiaceae. In: Kadereit JW (ed.), *The Families and Genera of Vascular Plants*, 7, 167-275. Springer, New York. https://doi.org/10.1007/978-3-642-18617-2_11
- Herralde, F.de., Savé, R., Biel C., Batlle I., & Vargas, F. J. (2001). Differences in drought tolerance in two almond cultivars: 'lauranne' and masbovera'. *Cahiers - Options Méditerranéennes*, 56, 149-154.
- Hetherington, A.M., & Woodward, F.I. (2003). The role of stomata in sensing and driving environmental changes. *Nature*, 424, 901-908. <https://doi.org/10.1038/nature01843>
- Hopkins, R., Schmitt, J., & Stinchcombe, J. R. (2008). A latitudinal cline and response to vernalization in leaf angle and morphology in *Arabidopsis thaliana* (Brassicaceae). *New Phytologist*, 179, 155-164. <https://doi.org/10.1111/j.1469-8137.2008.02447.x>
- Iturbe Ormaetxe, I., Escuredo, P.R., Arrese-Igor, C., & Becana, M. (1998). Oxidative damage in pea plants exposed to water deficit or paraquat. *Plant Physiology*, 116, 173-181. <https://doi.org/10.1104/pp.116.1.173>
- Jaleel, C.A., Manivannan, P., Lakshamanan, G.M., Gomathinayagamm, M., & Panneerselvam, R. (2008). Alterations in morphological parameters and photosynthetic pigment responses of *Catharanthus roseus* under soil water deficits. *Colloids and Surfaces B: Biointerfaces*, 61, 298-303. <https://doi.org/10.1016/j.colsurfb.2007.09.008>
- Kawamitsu, Y., Driscoll, T., & Boyer, J. S. (2000). Photosynthesis during desiccation in an Intertidal Alga and a Land Plant. *Plant Cell Physiology*, 41(3), 344-353. <https://doi.org/10.1093/pcp/41.3.344>
- Klamkowski, K., & Tender, W. (2008). Response to drought stress of three strawberry cultivars grown under greenhouse conditions. *Journal of Fruit and Ornamental Plant Research*, 16, 179-188.
- Kpyoarissis, A., Petropoulou, Y., & Manetas, Y. (1995). Summer survival of leaves in a soft-leaved shrub (*Phlomis fruticosa* L., Labiatae) under Mediterranean field conditions: avoidance of photoinhibitory damage through decreased chlorophyll contents. *Journal of Experimental Botany*, 46, 1825-1831. <https://doi.org/10.1093/jxb/46.12.1825>
- Kumar, A., Omae, H., Egawa, Y., Kashiwaba, K., & Shono, M. (2005). Influence of water and high temperature stresses on leaf water status of (*Phaseolus vulgaris* L.). *Japanese Journal of Tropical Agriculture*, 49, 109-118.
- Mafakheri, A., Siosemardeh, A., Bahramnejad, B., Struik, P.C., & Sohrabi, Y. (2010). Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Australian Journal of Crop Science*, 4(8), 580-585.
- Mahmood, S., Hayat, M.Q., Sadiq, A., Ishtiaq, Sh., Malik, S., & Ashraf, M. (2013). Antibacterial activity of *Lallemantia royleana* (Benth.) indigenous to Pakistan. *African Journal of Microbiology Research*, 7(31), 4006-4009.
- Manivannan, P., Abdul Jaleel, C., Sankar, B., Kishorekumar, A., Somasundaram, R., Lakshmanan, G.M.A., Panneerselvam, R. (2007). Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought-stress. *Colloids and Surfaces B: Biointerfaces*, 59, 141-149. <https://doi.org/10.1016/j.colsurfb.2007.05.002>
- Martin, D.L., Stegman, & E.C., Freres, E. (1990). Irrigation scheduling principles. In Hoffman, G.L., Howell, T.A., Solomon, K.H. (Eds), *Management of farm Irrigation Systems*. American Society of Agricultural Engineers Monograph, 155-372.
- Mohammad Khani, N., & Heidari, R. (2008). Effects of drought stress on soluble proteins in two maize varieties, *Turkish Biology*, 32, 23-30. <https://doi.org/10.2478/v10020-008-0029-8>
- Mousavi Nik, M., (2012). Effect of different levels of sulfur on yield and quality of *Plantago Ovate* L. under drought stress in Baluchistan region. *Agriculture Ecology*, 4(2), 170-182.
- Mssacci, A., Nabiev, S.M., Pietrosantl, L., Nematov, S.K., Chernikova, T.N., Thor, K., & Leipner, J. (2008). Response of photosynthetic apparatus of cotton (*Gossypium hirsutum*) to the onset of drought stress under field conditions studied by gas-exchange analysis and chlorophyll fluorescence imaging. *Plant Physiology and Biochemistry*, 46, 189-195. <https://doi.org/10.1016/j.plaphy.2007.10.006>
- Musallam, I.W., Al-Karaki, G.N., & Ereifej, K.I. (2004). Chemical rainfed and irrigation conditions. *International Journal of Agriculture and Biology*, 6, 359-362.
- Nagaz, K., Masmoudi, M.M., & Mechila, N.B. (2009). Yield and water use-efficiency of pearl millet (*Pennisetum glaucum* (L.) R. Br.) under deficit irrigation with saline water in arid conditions of Southern Tunisia. *Agronomy Journal*, 3, 9-17. <http://medwelljournals.com/abstract/?doi=rjagr.2009.9.17>
- Naghibi, F., Mosaddegh, M., Motamed, M.S., & Ghorbani, A. (2005). Labiatae family in folk medicine in Iran from ethnobotany to pharmacology. *Iranian Journal Pharmaceutical Research*, 2, 63-79.
- Nyachiro, J.M., Briggs, K.G., Hoddinott, J., & Johnson-Flanagan, A. M. (2001). Chlorophyll content, chlorophyll fluorescence and water deficit in spring wheat. *Cereal Research Communications*, 29, 135-142.
- Omidi H Shams H Seif Sahandi M Rajabian T. 2018. Balangu (*Lallemantia* sp.) growth and physiology under field drought conditions affecting plant medicinal content. *Plant Physiology and Biochemistry*, 130, 641-646. <https://doi.org/10.1016/j.plaphy.2018.08.014>
- Ommen, O.E., Donnelly, A., Vanhoutvin, S., van Oijen,

- M., & Manderscheid, R. (1999). Chlorophyll content of spring wheat flag leaves grown under elevated CO₂ concentrations and other environmental stresses within the ESPACE-wheat project. *European Journal of Agronomy*, 10, 197-203. [https://doi.org/10.1016/S1161-0301\(99\)00011-8](https://doi.org/10.1016/S1161-0301(99)00011-8)
- Pandey RK, Maranville JW & M.M. Chetima, (2000). Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth. *Agricultural Water Management*, 46, 15–27. [https://doi.org/10.1016/S0378-3774\(00\)00074-3](https://doi.org/10.1016/S0378-3774(00)00074-3)
- Parker, W. C., & Pallardy, S. G. (1985). Genotypic variation in tissue water relations of leaves and roots of black walnut (*Juglans nigra*) seedlings. *Physiologia Plantarum*, 64, 105-110. <https://doi.org/10.1111/j.1399-3054.1985.tb01219.x>
- Passioura, J.B., (1983). Roots and drought resistance. *Agricultural Water Management*, 7, 265–280. <https://doi.org/10.1016/B978-0-444-42214-9.50025-9>
- Rahimi, A., Jahansoz, M.R., Madah Hoseini, S., Sajjadnia, A.R, Roosta, H. R., & Fateh, E. (2011). Water use and water use efficiency of Isabgol (*Plantago ovata*) and French psyllium (*Plantago psyllium*) in different irrigation regimes. *Australian Journal of Crop Science*, 5(1), 71-77.
- Ramírez, D.A., Yactayo, W., Gutiérrez, R., Mares, V., De Mendiburu, F., Posadas, A., Quiroz, R. 2014 Chlorophyll concentration in leaves is an indicator of potato tuber yield in water-shortage conditions. *Scientia Horticulturae*, 168, 202-209. <https://doi.org/10.1016/j.scienta.2014.01.036>
- Rauf, S., & Sadaqat, H. A. (2008). Identification of physiological traits and genotypes combined to high achene yield in sunflower (*Helianthus annuus* L.) under contrasting water regimes. *Australian Journal of Crop Science*, 1, 23-30.
- Rechinqer, K.H. (1982). *Lallemantia (Labiatae) in Rechinqer Flora Iranica*, 150: Akademische Drurck U . Verlagsanstalt, Graz – Austria.
- Reddy, S.R. (1999). *Irrigation water management. In Principles of Agronomy* (Reddy S.R. Ed.), Kalyani publishers. New Delhi. 346-520
- Rivero, R.M., Kojima, M., Gepstein, A., Sakakibara, H., Mittler, R., & Gepstein, S. (2007). Delayed senescence induces extreme drought tolerance in a flowering plant. *Proceeding of the National Academy of sciences of the United States of America*, 104, 19631-19636. <https://doi.org/10.1073/pnas.0709453104>
- Romero-Romero, J. L., Inostroza-Blancheteau, C., Orellana, D., Aquea, F., Reyes-Díaz, M., Gil, P. M., Matte, J. P., Arce-Johnson, P. (2018). Stomata regulation by tissue-specific expression of the *Citrus sinensis* MYB61 transcription factor improves water-use efficiency in Arabidopsis. *Plant physiology and biochemistry*, 130, 54-60. <https://doi.org/10.1016/j.plaphy.2018.06.034>
- Rostamza, M., Chaichi, M.R., Jahansooz, M.R., & Alimadadi, A. (2011). Forage quality, water use and nitrogen utilization efficiencies of pearl millet (*Pennisetum americanum* L.) grows under different soil moisture and nitrogen levels. *Agricultural Water Management*, 98, 1607– 1614. <https://doi.org/10.1016/j.agwat.2011.05.014>
- Salehi, A., Tasdighi, H., Gholamhoseini, M. 2016. valuation of proline, chlorophyll, soluble sugar content and uptake of nutrients in the German chamomile (*Matricaria chamomilla* L.) under drought stress and organic fertilizer treatments. *Asian Pacific Journal of Tropical Biomedicine*, 6(10), 886-891. <https://doi.org/10.1016/j.apjtb.2016.08.009>
- Saraswathi, S.G., & Paliwal, K. (2011). Drought induced change in growth, leaf gas exchange and biomass production in *Albizia lebbek* and *Gassia siamea* seedlings. *Journal Environmental Biology*, 32, 173-178.
- Sarr, P.S., Khouma, M., Sene, M & Guisse, A. (2008). Effect of pearl millet-cowpea cropping systems nitrogen recovery, nitrogen use efficiency and biological fixation using the 15N tracer techniq. *Soil Science Plant Nutrition*, 54, 142-147. <https://doi.org/10.1111/j.1747-0765.2007.00216.x>
- Savé, R., Biel, C., Domingo, R., Ruiz-Sanchez, M.C., & Torrecillas, A. (1995). Some physiological and morphological characteristics of citrus plants for drought resistance. *Plant Science*, 110, 167-172. [https://doi.org/10.1016/0168-9452\(95\)04202-6](https://doi.org/10.1016/0168-9452(95)04202-6)
- Tashiro, T., & Wardlaw, I.F. (1990). The effect of high temperature at different stages of ripening on grain set, grain weight and grain dimensions in the semi-dwarf wheat 'Banks'. *Annual Botany*, 65, 51-61. <https://doi.org/10.1093/oxfordjournals.aob.a087908>
- Tennante, D. (1975). A test of modified intersect method of estimating root length. *Journal of Ecology*, 11, 995-1001. <https://doi.org/10.2307/2258617>
- Usher, G. (1974). *A Dictionary of Plants Used by Man*. Constable and Co. Ltd., London, UK., pp: 619.
- Weber, C.R., Shibles, R.M., & Byth, D.E. (1996). Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58, 99-102. <https://doi.org/10.2134/agronj1966.00021962005800010034x>
- Wentworth, M., Murchie, E.H., Gray, J.E., Villegas, D., Pastenes, C., Pinto, M., & Horton, P. (2006). Differential adaptation of two varieties of common bean to abiotic stress. II. Acclimation of photosynthesis. *Journal of Experimental Botany*, 57, 699- 709. <https://doi.org/10.1093/jxb/erj061>
- Winter, S.R., & Ohlrogge, A. J. (1993). Leaf angle, leaf area and corn yield. *Agronomy Journal*, 65, 395-397. <https://doi.org/10.2134/agronj1973.00021962006500030013x>
- Zargari, A. (1980). *Medical Plants*, pp. 113. Tehran: Tehran University Publication, Iran.
- Zegada-Lizarazu, W., & Iijima, M. (2005). Deep root water uptake ability and water use efficiency of pearl millet in comparison to other millet species. *Plant Production Science*, 8, 454–460. <https://doi.org/10.1626/pp.8.454>