CALCIUM CHLORIDE AND DROUGHT STRESS CHANGED GRAIN YIELD AND PHYSIOLOGICAL TRAITS IN SESAME (*SESAMUM INDICUM* L.)

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Water deficit or drought stress is one of the most significant abiotic stresses that induce reduction in plant growth and crops yield. Calcium chloride has been shown to ameliorate the adverse effects of drought stress on many plants. Therefore, this study aimed to investigate the role of calcium chloride in drought resistance and its effect on some physiological characteristics in sesame. Calcium is essential for good growth and structure of plants. In sesame (*Sesamum indicum* L.), the foliar application of calcium chloride (C_1=0 (control), C_2=5, C_3=10 and C_4=15 mM concentration) significantly affected on grain yield under drought stress (W_1= 7 (control, no drought stress-plants irrigation at a 7-day interval), W_2= 12 (severe drought and plants irrigation at a 12- day interval) and W_3= 17 (the most severe drought and plants irrigation at a 17-day interval). Drought stress reduced grain yield and 1000 seed weight, but these were enhanced by foliar application of calcium chloride when drought levels increased from W_1 to W_3. Although the increasing calcium chloride concentration reduced the content of photosynthesis pigments in leaves, the drought treatment until W_2 increased the content of photosynthetic pigments (chlorophyll "a" and carotenoids) in leaves. The foliar application of calcium chloride increased the seed weight in plant, the number of capsules per plant, plant height, and the concentration of potassium and phosphorus in leaves and seeds. The greatest amount of potassium in leaves and seeds were measured under the W_1C_3 treatment. Sesame plants under W_3C_3 and W_2C_3 had the highest amount of phosphorus in leaves and seeds, respectively. Overall, although drought stress reduced the growth and grain yield in sesame, the foliar application of calcium chloride at the concentration of 10 mM, prevented the drought-stressed sesame plants from damage by improving their physiological parameters.

Calcium chloride, Drought stress, Grain yield, Nutrient elements, Photosynthesis pigments, Sesame, Yield components

sciendo

doi: 10.2478/sab-2019-0029
Received for publication on July 9, 2018
Accepted for publication on September 17, 2019

INTRODUCTION

Water plays an important role in plant life. At many localities, it is the limiting factor for agricultural crops production. Water deficit induces a reduction in plant tissue water content with a subsequent reduction in water potential, leaf elongation, leaf photosynthesis and changes in protein synthesis, nitrogen metabolism and also a change in cell membrane properties (Shangguan et al., 2000).

Water deficit elicits several morphological responses in crop plants (Jones, 2004). Most of these responses are adaptive mechanisms to withstand water deficit or drought and to ensure both survival and reproduction under conditions of water deficit stress. There are three main aspects of plant morphological behaviour in relation to drought: the modulation of root growth (Jackson et al., 2000), the modulation of leaf size, and the changes in leaf orientation (Chaves et al., 2003). A fundamental problem with these adaptive responses is that most are aimed at reducing water use and consequently affect plant function and productivity through reduction in photosynthesis (Ribaut, 2006).

One of the effects of water deficit on plants are interferences with nutrient uptake. Generally, drought reduces both nutrient uptake by the roots and transport from the roots to shoots, because of restricted transpiration rates and impaired active transport and membrane permeability (Alam, 1999). Minerals are necessary for mediating biological responses of various enzymes. Sustainability of life is dependent upon a body's ability to provide balance between

Table 1. Weather conditions during experiment

	May	June	July	August	September
Average monthly temperature (°C)	21.7	26.8	27.7	27.7	24.9
Average monthly rainfall (mm)	5.2	0.6	80.4	54.5	49.9
Maximum monthly temperature (°C)	42.6	35	35.8	38	36.8
Minimum monthly temperature (°C)	12.8	18.8	19.4	20.2	13.8

the minerals (Prasad, Bisht, 2011). Among the nutrient elements, the role of calcium (Ca^{2+}) in plants is quite similar to that in animals and human; it is essential for good growth and structure. Calcium, in addition to its role in cell structure, also plays a role in regulating various cell and plant functions as a secondary messenger (Cousson, 2009). This function as a secondary messenger assists in various plant functions from nutrient uptake to changes in cell status to help the plant react to the impact of environmental and disease stresses. Several studies have showed that Ca^{2+} is involved in the regulation of plant responses to various environmental stresses (Colorado et al., 1994). It was found that treatment of maize seed with 15 and 20 mM Ca^{2+} solution enhanced the intrinsic heat tolerance of seedling (Gong et al., 1998). The external application of Ca^{2+} (5-10 mM) also reduced high temperature-induced membrane leakage in roots of sugar beet (*Beta vulgaris* L.) (Cookson, Earnshawf, 1986).

Xu et al. (2013) indicated that, under drought stress conditions, the dry weight and chlorophyll content of *Zoysia japonica* are generally thought to be important parameters for growth measurement. In that experiment, fresh biomass and below-ground dry biomass increased in all $CaCl_2$ pretreatment. These results suggest that Ca^{2+} plays an important role in alleviating the damage to zoysia grass incurred under drought conditions. Upadhyaya et al. (2011) also reported that using foliar sprayed $CaCl_2$ even after drought could enhance the dry mass of leaves in the recovery phase.

Sesame (*Sesamum indicum* L.) is a drought tolerant plant, however sensitive to drought at germination and seedling stages (Bahrami et al., 2012). *Sesamum indicum* L. (Pedaliaceae) is one of the oldest and important oil seed crops. It is usually cultivated in arid and semi-arid regions of the world for its quality edible oil (Eskandari et al., 2009) and it is very responsive to the changing environmental conditions. Therefore the objectives of this study were to investigate influence of water deficiency and examine the effects of external Ca^{2+} treatment on grain yield, yield components, mineral content and some physiological parameters in sesame.

MATERIALS AND METHODS

The field experiment was conducted at the research farm of Sari University of Agricultural Science and Natural Resources in Iran (latitude of 37° 45′ N and longitude of 54° 30′ E with an elevation of 13 m) in 2015. The field soil was clay loam in texture (pH, 7.4; electric conductivity (EC) 1.3 ds m^{-1}; content of organic carbon 1.04%; 0.10% N, 10.1 and 220 ppm of available P and K, respectively). The experiment was laid out as split plot based on randomized complete block design with three replications. There were three levels of drought stress: W_1= 7 (control or without drought stress, plants irrigation at a 7-day interval), W_2= 12 (severe drought, plants irrigation at a 12-day interval) and W_3= 17 day irrigation (the most severe drought, plants irrigation at a 17-day interval) as the main plots and four levels of calcium chloride concentration (in mM) for foliar application: C_1=0 (control), C_2=5, C_3=10 and C_4=15 mM (Xu et al., 2013) as the subplots. Weather conditions in Table 1.

Seed of the sesame cultivar ‘single branch of Naz’ were used in this study. There were five rows in each plot (3×4 m). The row width and length was 0.5 and 3 m, respectively. Before sowing, the soil was fertilized with N, P and K at the rate of 100, 50 and 50 kg ha^{-1} in form of urea, single super phosphate and potassium sulphate, respectively. A half of nitrogen was applied at sowing time and residue used after thinning plant. The seeds were sown on June 5th, 2015 and placed at 1-2 cm depth. The foliar application of calcium chloride was performed at the 8-10 leaves stage of plants.

Photosynthetic pigments and mineral content

At flowering stage (the flowering stage is one of the most sensitive stages to drought stress), the contents of chlorophyll ‘a’ and ‘b’ and total carotenoid in leaves were measured at 645, 663 and 440 nm spectrum absorptions, respectively according to Arnon’s (1967) method. The contents of nitrogen, phosphorus and potassium in leaves and seeds were determined by kejaldal (Gerhardt, Germany) method (AOAC, 2000), spectrophotometer (JENWAY 6105)

Table 2: Results of two-way analysis of variance (ANOVA) of drought stress and calcium chloride effects and their interaction for the parameters considered

Dependent variable	Independent variable		
	Drought (W)	Calcium chloride (C)	W*C
Grain yield	43599.2^{**}	2284.4^{**}	544.7^{**}
1000-seed weight	6.66**	2.55^{**}	1.19^{**}
Length of capsule	3.62^{**}	0.062^{*}	0.032^{ns}
Weight of capsule	0.0125^{**}	0.389^{**}	0.00156^{ns}
Seed weight per capsule	24.32^{ns}	6970.45^{**}	18.43^{ns}
Capsules per plant	1204.5^{ns}	1389.9^{**}	568.7^{ns}
Plant height	10.24^{ns}	6811.5^{**}	24.22^{ns}
Chlorophyll "a"	137.45^{**}	164.69^{**}	147.18^{**}
Chlorophyll "b"	52.44^{**}	63.14^{**}	28.76^{**}
Carotenoid	88.16^{**}	77.43^{**}	30.17^{*}
Phosphorus in leaves	0.133^{**}	0.061^{**}	0.22^{**}
Phosphorus in seed	0.0041^{**}	0.071^{**}	0.0003^{*}
Potassium in leaves	0.152^{**}	0.575^{**}	0.0151^{**}
Potassium in seed	0.052^{**}	0.156^{**}	0.0153^{**}

Numbers represent F values at 5% level, with indication of significance: * P≤0.05, ** P≤0.01, ns as not significant

and using a Jenway PF7 Flam photometer respectively (I m a m , 1996).

Grain yield and yield components

The sesame (*Sesamum indicum* L.) was harvested in September 14th, 2015. At maturity, to determine grain yield, the seeds of plants within the middle of central rows in each plot removed and cleaned. Then grain yield recorded. Yield had defined in terms of grams per square meter and quintals per hectare. Then plant height and yield components were calculated by using 5 plants per plot. The yield components included 1000-seed weight, number of capsules per plant, number of seed per capsule and length of capsules

Statistical analyses

All data were analyzed using SAS 9.2 software ((Statistical Analysis System, Version 9.2). All data were first analyzed by ANOVA to determine significant ($P \leq 0.05$) treatment effects. Significant differences between individual means were determined using Fisher's protected least significant difference (LSD) test.

RESULTS

Grain yield and yield components

The data statistical analysis showed that the interaction between two factors (drought stress and foliar application of calcium chloride) had a significant effect ($P < 0.01$) on grain yield (Table 2). Fig. 1 showed that, by increasing drought levels from W_1 to W_3, the grain yield was reduced. In this case, the foliar application of calcium chloride increased the grain yield of sesame plants. So that, at all levels of drought stress, the highest amount of grain yield was obtained at the highest levels of foliar application of calcium chloride (C_4=15 mM).The results showed that foliar application of calcium chloride can partially prevent the damage

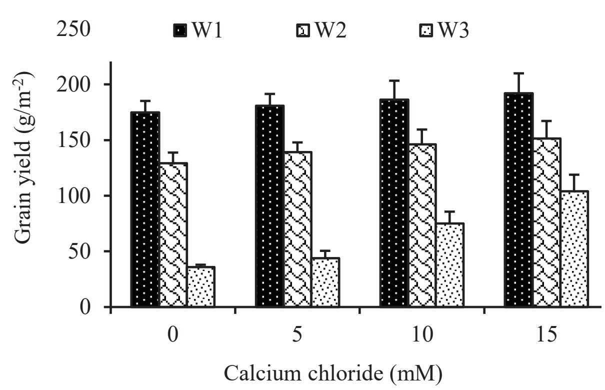

Fig. 1. Interaction between calcium chloride and drought stress on grain yield W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals)

Table 3. Yield components and plant height of sesame under drought stress and foliar application of calcium chloride

Treatments	Length of capsule (cm)	Weight of capsule (g)	Seed weight per capsule (g)	Capsules per plant	Plant height (cm)
Drought stress (day of irrigation)					
W_1= day 7	3.18a	56.91a	0.715a	107.1a	76.26a
W_2=day 12	2.544b	56.87a	0.679b	91.3ab	77.7a
W_3=day 17	2.085c	59.36a	0.651c	88.5b	76.1a
Calcium chloride (mM)					
C_1=0	2.53b	21.83d	0.433d	53.84c	44.55d
C_2=5	2.55b	53.67c	0.602c	74.93c	65.01c
C_3=10	2.60b	67.13b	0.781b	111.1b	90.01b
C_4=15	2.72b	88.22a	0.910a	142.7a	107.1a

Means followed by the same letter are not significantly different within rows and column according to Least Significant Difference (LSD) ($P \leq 0.05$)

of sesame grain yield from drought stress. At the W_1 treatment, by increasing foliar application of calcium chloride from C_1 to C_4, grain yield increased about 9.37%, at W_2 by14.7% and at W_3 treatment by 66.3%.

Among yield components, the interaction between the two factors (drought stress and foliar application of calcium chloride) had only significant effect on the 1000 seed weight (Table 2). In this study, it was found that drought stress reduced the weight of 1000 seed. By increasing drought stress from W_1 to W_3, the 1000 seed weight decreased but the foliar application of calcium chloride (even up to 15 mM, at all of drought stress treatments) improved it. The highest 1000 seed weight was obtained by the absence of drought stress or control (W_1) and by the foliar application of calcium chloride, even up to 15 mM (W_1C_4) treatment (Fig. 2).

The data statistical analysis (Table ۲) showed that the length and weight of capsule were affected by drought stress and calcium chloride treatments. Mean squares of data showed that by increasing drought levels from W_1 to W_3, the length and weight of capsule were decreased about 34.5% and 9.6% respectively (Table 3). In this cause, the foliar application of calcium chloride had a positive effect on those and increased them. By increasing the concentration calcium chloride from C_1 to C_4, the weight of capsule was increased linearly. About the length of capsules, this increase was obtained only at the highest calcium

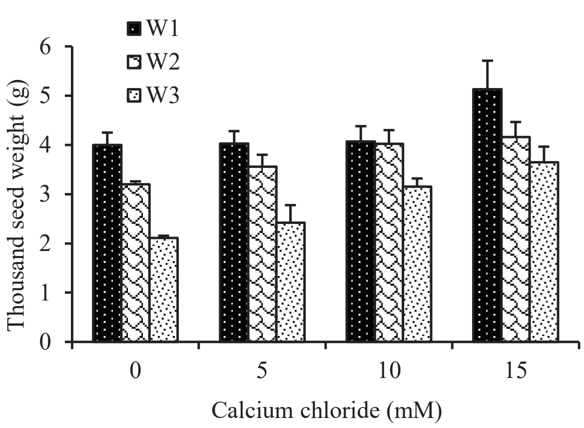

Fig. 2. Interaction between calcium chloride and drought stress on the weight of thousand seed

W1=7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

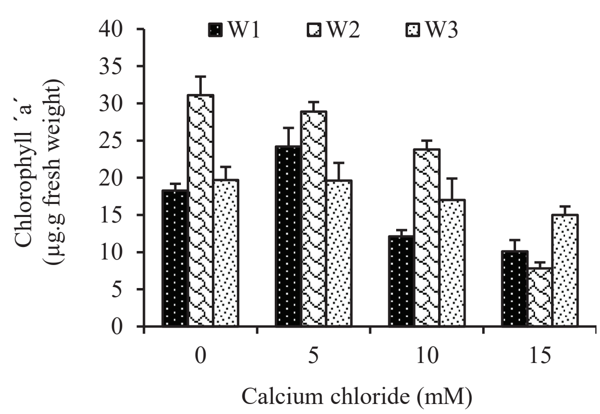

Fig. 3. Interaction between calcium chloride and drought stress on the content of chlorophyll ‘a’

W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

chloride treatment (C_4=15 mM) (Table 3). At the C_4 treatment, the weight of capsule was increased about 52.7% compared than C_1. This increase for the length of capsules was about 6.9% (Table 3).

Two treats of seed weight in plant and the number of capsule per plant plus the plant height were only influence by foliar application of calcium chloride (Table 2). The foliar application of calcium chloride increased these parameters and the best result was obtained by the C_4 treatment. C_4 treatment increased the seed weight in plant about 75.2%, the number of capsule per plant about 62.2% and the plant high 58.4% compared than C_1 treatment (Table 3).

Photosynthetic pigments

Statistical analysis showed that the interaction between two factors (drought stress and foliar application of calcium chloride) significantly effected the photosynthetic pigments, namely chlorophyll 'a'(Table 2).

The results showed that drought stress increased the amount of the chlorophyll 'a'. This increase lasted only up to W_2 treatment. Chlorophyll 'a' increased under the absence of the foliar application of calcium chloride. So the highest amount of chlorophyll 'a' was obtained at the W_2C_1 treatment (Fig. 3).

In this case, however calcium chloride improved the content of chlorophyll 'a' in leaves. But by increasing drought levels to W_3, the content of chlorophyll 'a' in leaf tissues decreased (Fig. 3). The results on chlorophyll 'b' and carotenoid showed that the interaction between the two factors (drought stress and foliar application of calcium chloride) had significant effect on chlorophyll 'b' and total carotenoid content in leaves (Table 2). The content of chlorophyll 'b'and total carotenoid were increased when drought level increased from W_1 to W_3. The highest chlorophyll 'b'and carotenoid content were obtained at W_3 and W_2 respectively. When foliar calcium chloride was applied, the content of these two photosynthetic pigments decreased. Therefore, the highest amount of chlorophyll 'b' and carotenoid contents in leaves were obtained at W_3C_1 and W_2C_1 respectively (Figs. 4 and 5).

Mineral content

Concerning mineral elements, increasing drought stress and foliar applications levels of calcium chloride increased the content of phosphorus and potassium in leaves and seed.

Potassium in leaves and seed was most abundant at the W_1C_3, phosphorus in leaves attained the highest levels at W_3C_3 and in the seed at W_2C_3 treatment (Figs. 6-9).

DISCUSSIONS

Water stress adversely affects plant establishment and therefore growth and development. Water stress reduces plant growth by affecting various physiological and biochemical processes such as photosynthesis, respiration, translocation, ion uptake, nutrient metabolism and growth promoters (J a l e e l et al., 2008). Water stress in plants reduces water potential and turgor, which elevate the solutes concentrations in the cytosol and extracellular matrices (H e i d a r i , G o l p a y e g a n i , 2012). Drought not only affects plant

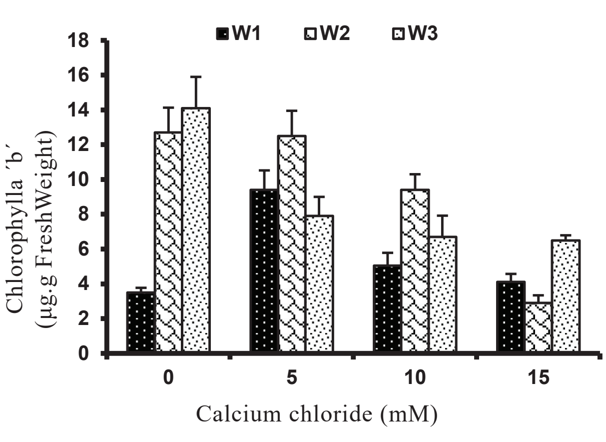

Fig. 4. Interaction between calcium chloride and drought stress on the content of chlorophyll 'b'
W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

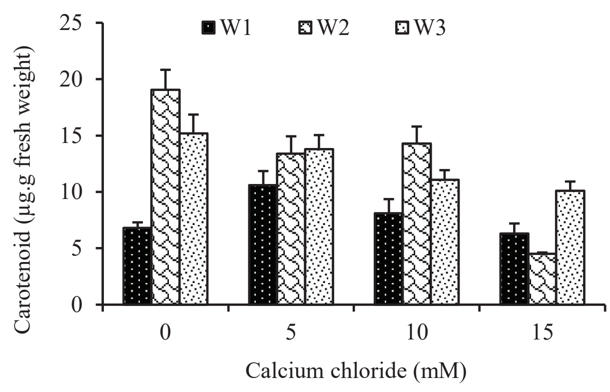

Fig. 5. Interaction between calcium chloride and drought stress on the content of carotenoid
W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

water conditions, but also mineral nutrition (uptake and transport of nutrients) and metabolism leading to a decrease in the grain yield (Soares-Cordeiro et al., 2009)

In this study has shown that drought stress reduced growth and grain yield of sesame plants. As seen in Fig.1, with increasing drought levels from W_1 (control) to W_3 (the most severe drought), the grain yield of sesame decreased. Yield loss can be due to various reasons. In this study, changes in chlorophyll and photosynthesis consequently less effective in grain yield reducing, because sesame is partly resistant to drought (Heidari, Karami, 2014). So, the loss causes of grain yield in this study by drought stress, can be relate to the impact of drought stress on other traits such as changes in the absorption of nutrient elements, as well as changes in the yield components (Table 3).

The primary yield components of sesame are biological yield, 1000-seed weight, the seed weight in plant and the number of capsules per plant. Even though, yield components are under genetic control,

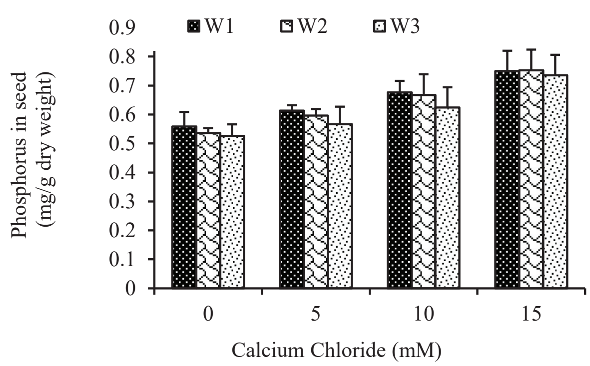

Fig. 6. Interaction between calcium chloride and drought stress on the amount of phosphorus in seed

W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

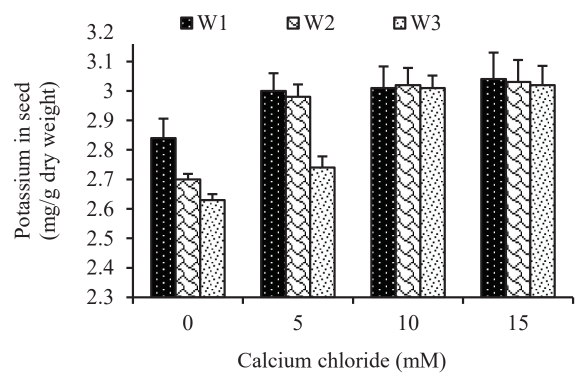

Fig. 7. Interaction between calcium chloride and drought stress on the amount of potassium in seed

W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

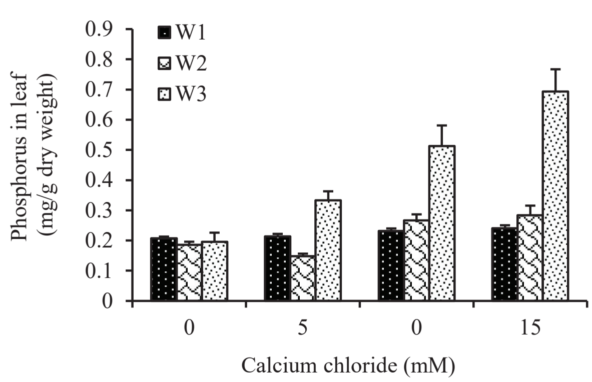

Fig. 8. Interaction between calcium chloride and drought stress on the amount of phosphorus in leaves

W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

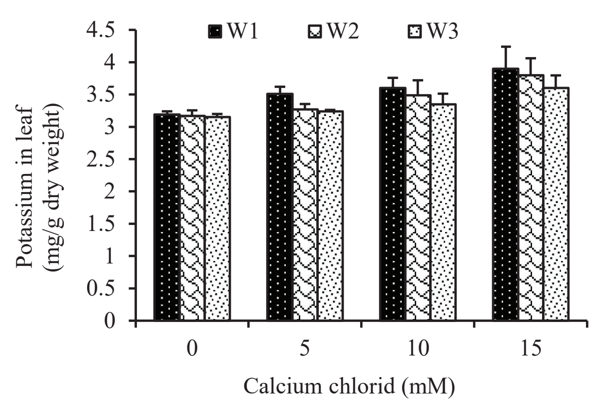

Fig. 9. Interaction between calcium chloride and drought stress on the amount of potassium in leaves

W1= 7 (control or without drought stress and plants irrigation at 7-day intervals), W2= 12 (severe drought and plants irrigation at 12-day intervals) and W3= 17 day irrigation (the most severe drought and plants irrigation at 17-day intervals

they do respond with various degree of flexibility to water deficit or irrigation regime (Nabipour et al., 2007). The rresults of statistical analysis of variance indicates that drought stress had significantly effect on yield components and nutrient elements in sesame (Table 2).

In the present case, the foliar application of calcium chloride improved the growth rates, photosynthetic pigments, absorption of nutrient elements and eventually enhanced grain yield in sesame plants (Table 3). Importantly, calcium is involved in the regulatory mechanisms activating the plants to adjust to adverse environmental conditions of drought stress (Shao et al., 2008). Further, calcium has been shown to ameliorate the adverse effects of water stress on plants and involved in signaling anti-drought responses (Shao et al., 2008). Calcium appears to play a key role in many defense mechanisms that are induced by drought, and Ca^{2+} signaling is required for the acquisition of drought tolerance or resistance (Cousson, 2009).

In this study, however, the highest amount of chlorophyll 'a', chlorophyll 'b' and carotenoid in leaves were obtained at the C_1 treatment (without the application of calcium chloride), but calcium chloride increased the concentration of potassium and phosphorus in leaves and seeds of sesame plants. At the drought levels, the greatest amount of potassium in leaf and seed were obtained at the W_1C_3 while of phosphorus at W_3C_3 and W_2C_3. It can be stated that although drought stress reduced growth and grain yield in sesame, the foliar application of calcium chloride prevented the drought- stress sesame plants from damage by improving their physiological parameters. It seems that the applied $CaCl_2$ might prevent damage from cellular dehydration by balancing the osmotic strength of the cytoplasm (Arshi et al., 2006). At the drought levels, however the highest values for some traits measured in this study were obtained in the C_4 treatment (grain yield and 1000 seed weight), but C_3 treatment had similar C_4 treatment.

CONCLUSIONS

Drought stress has an adverse effect on many crops. Depending on the species, its impact intensity varies. Although sesame is one of drought stress resistant crops, the present study indicated that drought stress had negatively affected its growth and grain yield. Drought reduced grain yield and 1000 seed weight. This decrease was also partly due to the negative effect of drought stress on some physiological traits (photosynthetic pigments and absorption of nutrient elements).

Under environmental conditions of drought stress, the use of compounds such as calcium can, by improving the absorption of water and nutrients, prevent the plants from drought stress effects. In this study, the foliar application of calcium chloride increased the seed weight in plant, the number of capsules per plant, plant height and the concentration of potassium and phosphorus in leaves and seed. To conclude, during drought stress conditions, the foliar application of 10 mM calcium chloride may prevent sesame plants from the adverse effects of drought.

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