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Original Research

The effect of salicylic acid and potassium sulphate on safflower (*Carthamus tinctorius*) yield under the water stress

Authors:
Afsoon Tayebi[1], Farhad Farahvash[2], Bahram Mirshekari[2], Mehrdad Yarnia[2] and Alireza Tari-nejad[3]

Institution:
1. Agronomy, Tabriz Branch, Islamic Azad University, Tabriz, Iran.

2. Department of Agronomy and Plant Breeding, Tabriz Branch, Islamic Azad University, Tabriz, Iran.

3. Department of Agricultural Biotechnology, Azarbaijan Shahid Madani University, Tabriz, Iran.

Corresponding author:
Farhad Farahvash

ABSTRACT:

Physiological stress indicates the environmental pressures which affect the plant physiology and change it. The experiment was conducted as split plot in randomized complete block design with three replications on safflower (*Carthamus tinctorius*) from 2015 to 2016. Treatments were: 1) Irrigation: without stress (irrigation after 70 mm evaporation from evaporation pan class A) and drought stress (irrigation after 150 mm evaporation from pan class A) was considered as the main factor and the concentration of salicylic acid with three levels (0.100 and 200 mg L^{-1}) as the first sub-factor. The second sub-factor includes the concentrations of three levels of potassium sulphate (0.05 and 1 mg L^{-1}). The interaction between drought stress and potassium sulphate and also potassium sulphate and salicylic acid were significant on the induction of plant height. With regard to this, the comparison between salicylic acid and potassium sulphate interaction on the safflower plant height and the highest plant height (107.3 cm) was obtained by using 200 mg salicylic acid plus 1 mg L^{-1} of potassium sulphate. The combined analysis of data indicated that interaction between potassium sulphate × salicylic acid on the grain yield was significant. The highest grain yield (1550 kg ha^{-1}) belonged to the foliar application of 100 mg salicylic acid and 0.5 mg L^{-1} of potassium sulphate interaction. The interaction of salicylic acid and potassium sulphate was significant on the biological yield, and the highest biological yield was obtained with 200 mg L^{-1} of salicylic acid and 0.5 mg L^{-1} of potassium sulphate. Therefore, in order to compensate for some of the harmful effects of stress and enable the plant to return to normal growing conditions after re-watering, foliar application of such chemical compounds on plant can be effective and plays an important role on the resistance of plant to drought.

Keywords:
Carthamus tinctorius, salicylic acid, potassium, drought

Email Id:
farahvash@iaut.ac.ir

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INTRODUCTION

Stress is the exposure of an organism to an intensity of environmental factor which causes apparent loss in its efficiency or value. Physiological stress indicates the environmental pressures which affect the plant physiology and change it. The reduction in performance is affected by genotype, severity of water shortages, and the plant growth stage. Among the oilseeds adapted to Iran's situation, being a drought and salinity-resistant plant (Bassil and Kaffka, 2002) and by having spring and autumn species, *Carthamus tinctorius* has a promising future. In vegetative stage, drought stress reduces the production of dry matter and plant performance by reducing the leaf area index.

In growth stage, safflower is more tolerant to water scarcity rather than the subsequent stages, and absence of irrigation at this stage helps to develop the plant root system and increases the resistance to hot and dry conditions in the next stage. It is therefore recommended that after safflower germination and establishment, it should be exposed to a short dry period (Khajehpour, 2006). Proper nutrition under stress condition can help the plant somewhat to tolerate different stresses. Potassium is one of the main macronutrients that its effect is proven on photosynthesis, also tolerant against environmental stresses and enhancing irrigation efficiency (Fageria, 2002). Fugger and Malakouti (2000) stated that potassium in addition to increasing production and improving the quality of product, causes increase in plant tolerance to salinity, drought, different types of stress, pests and diseases, and will increase the efficiency of water and nutrient usage.

Salicylic acid or benzoic ortho-hydroxy is a phenolic compound that is found in the nature and is abundant in numerous plant tissues (Hayat and Ahmad, 2007). Currently, this combination is considered as a hormone-like substance that plays a vital role in the growth and development of the plants (Kang *et al.*, 2003). In most studies, the most important action of salicylic acid is stated as response and resistance to some stresses such as drought and salinity (El-Tayeb, 2005; Noreen and Ashraf, 2008). A variety of salicylic acid physiological and biochemical effects on the plant systems are observed which include ion absorption, seeds germination, membrane permeability, mitochondrial respiration, stomata closure, material handling, growth and photosynthesis rate (Senaratna, 2003).

Safflower has very diverse figures that are different in terms of flower color, plant height, leaf shape, stem shape, being acanaceous, oil content, fatty acid composition, duration of growing season, grain weight and other characteristics. Mousavifar *et al.* (2009) by studying the effect of shortage of irrigation at the reproductive growth stages in spring safflower, found that there is a significant difference between the three local variety of Isfahan, Isfahan 28 and IL111, in terms of seeds number and different classification. Furthermore, by increasing the duration of irrigation, seeds number decreased in all three varieties. Reduction in the seeds number could be due to the impact of water shortage on the flowers pollination and abortion (Bradford, 1993). According to the safflower cultivation new programs, only little information is available regarding new varieties of safflower response to environmental stress in the country.

This study is aimed at investigating the response of safflower to drought stress, as well as finding a method that could produce the highest yield with less water thereby resulting in lower production costs.

Hypotheses

- Application of salicylic acid causes to resistance to drought.
- Application of potassium sulphate causes to resistance to drought.
- Drought has various effects on the safflower yield.

MATERIALS AND METHODS

This experiment was conducted in 2015 and 2016 at the Agricultural Faculty of Tabriz Islamic Azad University (38^o 7' E, 46^o 20' N, and 1361 m). This experiment was conducted as split plot in randomized complete block design with three replications on safflower (cv. safe). Irrigation with two levels: without stress (irrigation after 70 mm evaporation from evaporation pan class A) drought stress (irrigation after 150 mm evaporation from pan class A) and is considered as the main factor and the concentration of salicylic acid with three levels (zero, 100 and 200 mg L^{-1}) as the first sub-factor. The second sub-factor includes the concentrations of three levels of potassium sulphate (0. 0.5 and 1 mg per liter).

Each experimental unit (plot) with a length of 3 m comprises five rows, by 50 cm row spacing and 10 cm seeds row spacing. Irrigation of farm was done for water drought treatment (in the 7-8 leaf stage) in the same manner and every seven days for all plots and then drought stress is applied based on evaporation pan. Salicylic acid and foliar application of potassium sulphate was done in the 7-8 leaf stage and a week prior to the drought stress.

At harvest time, the five plants in each experimental plot were selected randomly by considering the marginal effects, and the traits such as plant height, number of secondary branches, number of heads per plant, number of seeds per head and thousand seeds weight were measured and recorded. The plants in the area of 4 m^2 per plot were selected separately to determine the yield and after separation of the seeds, seeds weight and yield were calculated by precision scale in kilograms per hectare.

In this study, SAS (2002) software and Excel software (2016) were employed for data analysis and drawing of diagram, respectively. Mean comparisons were carried out using LSD at 5% level.

RESULTS AND DISCUSSION

Plant height

Results revealed that the year and drought stress interaction were significant on the safflower plant height which shows that the growth of safflower varied under drought stress conditions in different years. Comparing the height average in 2015 and 2016 and various stresses demonstrated that in both years, plant height was reduced by increasing drought stress, but this reduction was 33.69% in the first year and 13.13% in the second year, respectively (Table 1). Salem and colleagues (2014) also observed that water stress reduced plant height considerably. Although the growth phenomenon is the result of vital activity in a condition that the plant should have sufficient water, if there is lack of water supply, the height will decrease owing to the reduced turgor pressure in growing cells and its impact on the cells (Munns and Tester, 2008). The interaction between drought stress and potassium sulphate and also potassium sulphate and salicylic acid was significant on plant height. Comparison between the average plant height influenced

Table 1. Comparison of safflower traits influenced by the year and drought stress interaction in the combined biennial analysis

S. No	Year	Drought stress (evaporation mm)	plant height (cm)	Head number in plant	Number of secondary branches	Number of seeds in plant	Biological yield (kg ha^{-1})
1	2015	70	^{a} 127.8	^{a} 47.40	^{a} 45.51	^{a} 3559	^{b} 30.62
		140	^{c} 84.74	^{b} 16.70	^{b} 14.56	^{b} 1179	^{d} 19.92
2	2016	70	^{b} 101.6	^{b} 22.60	^{b} 18.60	^{b} 1835	^{a} 44.84
		140	^{c} 88.26	^{b} 21.89	^{b} 16.41	^{b} 1816	^{c} 23.41

Means with different letters in a column are statistically significant (LSD test; p £ 0.05).

Table 2. Comparison of safflower traits influenced by drought stress and salicylic acid interaction in the combined biennial analysis

S. No	Drought stress (evaporation mm)	salicylic acid (mg L^{-1})	Head number in plant	Number of secondary branches	Number of seeds in plant	grain yield (Kg per hectare)
1	70	0	31.28[b]	28.68[b]	2260[bc]	1324[b]
		100	45.24[a]	38.14[a]	3490[a]	1779[a]
		200	28.54[b]	26.06[b]	2340[b]	1174[bc]
2	140	0	18.16[d]	18.19[cd]	1329[d]	921.2[cd]
		100	15.72[d]	12.51[d]	1136[d]	721.1[d]
		200	23.99[c]	19.04[c]	2026[c]	1206[bc]

In each column, the means having at least one letter in common have no significant difference based on LSD test at 5% p-value

by drought stress treatments and potassium sulphate showed that drought stress treatment based on 70 mm evaporation and the use of 0.5 mg per liter of potassium sulphate causes 6.28% increase in plant height rather than lack of it.

The use of 1 mg per liter of potassium sulphate reduced plant height compared to the control, which of course was not statistically significant. In drought stress treatment based on 140 mm evaporation, different levels of potassium sulphate did not cause significant changes in this trait (Table 3). As regards the comparison between salicylic acid and potassium sulphate interaction on the safflower plant height, the highest plant height (107.3 cm) was obtained in the treatment by using 200 mg salicylic acid plus 1 mg per liter of potassium sulphate, and the lowest (93.81 cm) for the treatment by not using salicylic acid and 1 mg per liter of potassium sulphate, which statistically was not significantly different from the control (no foliar application of salicylic acid and potassium sulphate), (Table 4). One of the reasons for the improvement in plant growth which is influenced by salicylic acid treatment is the effect of salicylic acid on the plant mineral nutrition which has been mentioned in diverse studies (El-Tayeb, 2005; Khan *et al*., 2003). Gunes *et al.* (2005) reported that salicylic acid causes increase in cations, including potassium in corn in various stresses.

Number of secondary branches

The number of secondary branches trait in the plant, plays a key role in terms of the number of head formation per plant, number of seeds per head and seed yield. According to the results of the analysis, the drought and the number of secondary branches interaction was significant in the plant. The number of secondary branches in the first year (2015) and in drought stress treatment was higher than the other treatments based on 70 mm evaporation. Mean comparisons of the year × drought stress interaction indicated that the increased drought led to reduction in the number of branches in plant, in a way that its amount in the drought stress in the first year based on 140 mm evaporation compared with the control group, decreased by 68% in the first year and 11.77% in the second year, in which this reduction in the second year was not statistically significant (Table 1). Under increasing irrigation intervals, the initial cells number reduces to produce primary branches stems and consequently, leads to secondary branches reduction per plant (Cox and Jollif, 1984). The water and salicylic acid stress interaction was significant on the number of secondary branches. The numbers of secondary branches were different from 38.14 in the stress level, 70 mm evaporation and 100 mg L^{-1} to 12.51 in drought stress, 140 mm evaporation and 100 mg L^{-1} (Table 2).

Table 3. Comparison of safflower traits influenced by drought stress and potassium sulphate interaction in the combined biennial analysis

S. No	Drought stress (evaporation mm)	Potassium sulphate (mg L^{-1})	Plant height (cm)	Biological yield (kg per hectare)
1	70	0	113.0^{b}	38.85^{a}
		0.5	120.1^{a}	37.80^{a}
		1	110.9^{b}	36.50^{a}
2	140	0	85.99^{c}	18.10^{c}
		0.5	84.83^{c}	26.30^{b}
		1	88.68^{c}	20.50^{c}

In each column, the means having at least one letter in common have no significant difference based on LSD test at 5% p-value

Head number in plant

The head number per plant is affected by drought stress × year interaction and the heads maximum number per plant (47.40) was obtained in the first year and drought stress based on 70 mm evaporation respectively. Head number in plant was not significantly different in the second year and in diverse stress tests (Table 1). The heads numbers per plant are significantly affected by two factors: drought and concentration of salicylic acid (Table 2), so that the greatest number of heads per plant is observed with an average of 45.24 under 70 mm evaporation and 100 mg of salicylic acid per liter.

Furthermore, the heads minimum number per plant belonged to drought stress based on 140 mm evaporation and 100 mg L^{-1} of salicylic acid by the average of 15.72. In drought stress, based on 140 mg evaporation, consumption of 200 mg salicylic acid compared with 100 mg of salicylic acid increased the number of heads per plant by 52.60%, but drought treatment on 70 mm evaporation by consuming the same amount of salicylic acid decreased the number of heads per plant by 58.51%, respectively.

According to the average levels of potassium sulphate foliar application Table at any level of salicylic-acid (Table 4), in the absence of salicylic acid, the highest number per plant belonged to foliar application of potassium sulphate at the rate of 30.37 with 1 mg per liter concentration, and the lowest number belonged to foliar application of potassium sulphate at the rate of 21.27 with a concentration of 0.5 mg per liter. In foliar application of salicylic acid with a concentration of 100 milligrams per liter, the highest number per plant belonged to the foliar application of potassium sulphate at the rate of 26.95 with a concentration of 1 mg per liter, and the lowest number belonged to the absence of foliar application of potassium sulphate with the rate of 20.88 respectively. Thus, there was no significant difference with 0.5 milligrams per liter of potassium sulphate. In foliar application of salicylic acid at a concentration of 200 milligrams per liter, the highest head number per plant was observed with the rate of 29.75 in the absence of foliar application of potassium sulphate.

Grain yield

According to the average levels of salicylic acid foliar application Table at any level of drought stress (Table 2), the highest grain yield was obtained as 1779 kg per hectare in drought stress based on 70 mm evaporation and salicylic acid foliar application of 100 mg per liter. Moreover, the lowest yield (721.1 kg ha^{-1}) was obtained under drought stress based on 140 mm evaporation and salicylic acid foliar application of 100 mg, in which it was not significant compared with the absence of foliar application on the same stress level.

Table 4. Comparison of safflower traits influenced by salicylic acid and potassium sulphate interaction in the combined biennial analysis

S. No	Salicylic acid (mg L^{-1})	Potassium sulphate (mg L^{-1})	Plant height (cm)	Head number in plant	Secondary branches number	Seed number in plant	Seed yield (kg per hectare)	Biological yield (kg per hectare)
1	0	0	97.23^{cd}	27.45^{bc}	23.06^{bc}	1713^{d}	985.9^{c}	29.50^{bc}
		0.5	104.9^{ab}	21.27^{e}	22.65^{bc}	1509^{d}	992.4^{c}	27.70^{c}
		1	93.81^{d}	39.37^{a}	24.61^{abc}	2162^{bc}	1389^{ab}	33.70^{ab}
2	100	0	99.63^{c}	20.88^{e}	29.39^{ab}	2246^{b}	1273^{abc}	29.50^{bc}
		0.5	97.21^{cd}	22.09^{e}	31.28^{a}	3195^{a}	1550^{a}	31.30^{bc}
		1	98.42^{cd}	26.95^{bcd}	15.30^{d}	1499^{d}	925.1^{c}	20.10^{d}
3	200	0	101.7^{bc}	29.75^{b}	19.01^{cd}	1836^{cd}	1132^{bc}	26.50^{c}
		0.5	105.3^{ab}	22.65^{de}	24.21^{bc}	2272^{b}	1142^{bc}	37.10^{a}
		1	107.3^{a}	24.61^{cde}	24.41^{abc}	2441^{b}	1293^{abc}	31.90^{abc}

In each column, the means having at least one letter in common have no significant difference based on LSD test at 5% p-value

In irrigation treatment based on 140 mm evaporation, the difference between the lowest yield was in the treatment of salicylic acid foliar application of 100 mg per liter, and the highest yield was in the foliar application of 200 milligrams per liter as 484.9 kg ha^{-1}, respectively which indicated an increase of 67.24% in the grain yield, whereas the difference between the lowest and highest yield was based on 70 mm evaporation resulting from different levels of salicylic acid in the stress treatment as 455 k/ha in which the rate showed the increase of 34.36% in grain yield influenced by these treatments interactions (Table 2).

The combined analysis of data indicated that interaction between potassium sulphate × salicylic acid on the grain yield was significant. The highest grain yield (1550) belonged to the foliar application of 100 mg L^{-1} salicylic acid and 0.5 mg L^{-1} of potassium sulphate interaction. Also, the lowest grain yield (925.1 kg ha^{-1}) belonged to the foliar application of salicylic acid at the same level and 1 mg L^{-1} of potassium sulphate, respectively (Table 4).

Salicylic acid has a positive effect on photosynthesis and plants growth under stress conditions. It appears that salicylic acid causes a significant increase in yield and its components by regulating physiological and biochemical processes in the face of biotic and abiotic stresses during the plant life (Ghoraba and Farahbakhsh, 2014).

Moreover, numerous reports showed the positive effect of potassium on grain yield in different plants and under drought stress (Reza *et al*., 2014; Valadabadi and Farahani, 2010). Given the important role of potassium in increasing the rate of photosynthesis, absorption of carbon dioxide and facilitating the carbon transfer process from resources to the tanks, it resulted in an increase in the grain yield. Potassium plays a vital role in the processes related to the enzymes activity, photosynthesis, transformation of sugars, protein synthesis, starch, establishment of plants under drought stress, by setting up speed and opening and closing of stomata, improving resistance to lodging and pests and diseases attacks that in this way has a direct effect on the yield per plant (Jiang *et al*., 2011).

Biological yield

But the comparison of the year × drought interaction (Table 1) shows that the total amount of biomass between treatments in the second year (2016) was higher than in the first year (2015), and its maximum value (44.84 kg/ha) based on 70 mm evaporation belonged to the second year and the drought stress, respectively.

Results revealed that the stress and potassium sulphate interaction was significant on the biological yield. According to the mean comparisons, drought stress causes reduction in biological yield compared to the 70 mm evaporation, but the use of potassium sulphate reduced the negative impact of stress on biological yield significantly, although the increased rate owing to the usage of potassium sulphate in the stress levels of 140 mm evaporation did not result in biological yield as the control level without potassium sulphate (Table 3). The interaction of salicylic acid and potassium sulphate was significant on the biological yield, and the highest biological yield was obtained with 200 mg per liter of salicylic acid and 0.5 mg L^{-1} of potassium sulphate, respectively. The lowest amount of this trait is related to the treatment of 100 mg of acetylsalicylic acid and 1 mg of potassium sulphate (Table 4).

During drought stress, plants close their stomata thereby reducing the amount of carbonation and photosynthesis. Furthermore, it causes reduction in the cell turgor and prevents the cell division in which these factors cause reduced plant growth and biological yield (Malakouti *et al*., 2008). Lack of soil moisture leads to reduction in nutrient delivery to the plant's root level which prevents adequate nutrients absorption by them, so that the plants will suffer lack of water along with food. It is possible to improve nutrient uptake by using salicylic acid under drought conditions, which in turn would increase the growth and the biological yield (Ghoraba and Farahbakhsh, 2014).

Also, potassium sulphate in this study had a significant effect on biological yield. The effect of potassium on growth is due to the fact that the element plays an important role in hydrocarbons production in plants, and potassium deficiency in plants is associated with reduced photosynthesis and increased plant respiration. Hydrocarbon reduction in plant reduces the accumulation of dry matter owing to changes in photosynthesis and respiration.

CONCLUSION

In general, the results revealed that the highest yield and its components were achieved by favorable irrigation. Although foliar application by salicylic acid causes increase in most growth indices and consequently increases the yield in non-stress conditions, but does not have any significant effect on grain yield in drought stress conditions. Therefore, in drought stress conditions, it will be impossible to reduce the negative effects of stress on grain yield through the application of salicylic acid but the use of small amount of salicylic acid (100 mg per liter) can somewhat increase the devastating effects of drought on plant growth. In contrast, high potassium levels can be used as a mineral osmolyte in the osmotic regulation under severe conditions and can have the higher share rather than organic osmolytes. Therefore, in order to compensate for some of the harmful effects of stress and enable the plant to return to normal growing conditions after re-watering, foliar application of such chemical compounds on plant can be effective and plays an important role on the resistance of plant to drought.

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