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Research Article

Effect of Silicon Nutrition on Yield and Physiological Characteristics of Canola*(Brassica napus)* under Water Stress Conditions

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ABSTRACT

Approximately four-fifths of the land areas of the world are located in arid and semi-arid areas. There is too much precipitation in Iran which its average annual rainfall is about 260 mm representing drought phenomenon in Iran is a climatic reality.Canola is of particular importance so that it is considered as the second important world edible oil producer after the Soybean. In this plant, flowering and pod formation are the most sensitive stages to the drought stress which are faced with drought stress in the most agricultural areas of the country. Moreover,previous studies are mainly focused on the reducing effects of drought stress on the agronomical and physiological traits of crops. On the other hand, there have been large numbers of studies which are emphasized on improving impact of silicon on drought stress effects of crops to offset. In addition, some split plots in a randomized complete blocks with four replications were designed and implemented in the agricultural year 2014-2015 in order to investigate the effect of siliconnitrition on the resistance to the drought of the experimental Canola plant.There were certain Experimental treatments including drought stress in two level e.g. normal irrigation (control) and drought stress considered as the major factors and then silicon spray on levels of 0, 1 and 1.5 mM considered as the minor factors. The results indicated that drought stress could cause to reduce the investigated traits such as yield. Furthermore, it revealed that acid silicon spray could result in increased investigated traits. Also, there was a significant correlation between the drought stress and silicon spray. By doing mean comparisons, it was observed that silicon spray considerably caused to offset of drought stress effects. On the other hand, it also had a positive effect on the investigated traits under the normal irrigation conditions. Thus, it could be recommended applying silicon spray for Canola crop.

Keywords: drought stress, silicon, Canola, physiological characteristics, yield

INTRODUCTION

Approximately four-fifths of the land areas of the world are located in arid and semi-arid areas (ZebarJady et al, 2010). Iran has arid and semi-arid climate and it also its average precipitation is around 240 mm which is two-third of the global mean rainfall, therefore, it is affected by drought stress and periodic droughts (AkbariMoghaddam, 2012). There is too much precipitation in Iran which its average annual rainfall is about 260 mm representing drought phenomenon in Iran is a climatic reality (MoslehArany et al, 2012). Environmental stress is the most important global reducing factors of plant productions. Environmental stress cause to eliminate the balance of growing Reactive Oxygen Species (ROS) in different parts of plant (Bai and Sui, 2006).Drought and salinity are the most important environmental stress in arid and semi-arid areas of Iran (YazdaniBiouki and RezvaniMoghadam, 2012). If the received water of plant is less than its waste, drought stress will occur in the plant which may be because of exceeding water waste or reduction or both (Al-Ebrahim et al, 2005). Low rate of precipitation and its irregular distribution would lead to drought stress during the crops growing period (Gupta, 2001). Drought and its stress are the most important and common environmental stress which annually cause to notable damages to these crops in the world particularly in Iran as it is known as an arid and semi-arid country (Sabbaghpour, 2003).

Canola is referred as the second substantial edible oil resource followed by the sotbean (FAO, 2007). In this plant, flowering and pod formation are the most sensitive stages to the drought stress which are faced with drought stress in the most agricultural areas of the country (Sinaki et al, 2007). Drought stress is considered as the main reason of the reduction of plant growth and their yield over the arid and semi-arid areas which provoke the crop to show certain defense responses on various levels including molecular, cellular, and physiological and growth (Haddad and SalekJalali, 2009). It seems that drought stress and water reduction in plant tissues could result in growth reduction, stomata closure, photosynthesis reduction, affecting the respiration, proteins and enzymes damage and proline accumulation (Tale Ahmad and Haddad, 2007; Yadollahi et al, 2014a; Yadollahi et al, 2014b; Shamsi, 2010; Tayebi et al, 2012). Hence, water reduction cause chlorophyll to break and glutamate which is a precursor of chlorophyll and proline is transformed into the proline under the influence of this stress and finally, the chlorophyll content will decrease (Lawlor and Cornic, 2002). Based on this, a great number of researchers have confirmed the negative and reducing effect of drought stress on yield and yieldal elements, a and b chlorophylls, protein and proline (Mohammadi et al, 2006; Mohammadi et la, 2011; Saeedi et al, 2010; Tale Ahmad and Haddad, 2008; Yadollahi et al, 2014b; Tale Ahmad and Haddad, 2010). Since plants periodically face diverse environmental stress such as drought and salinity, in this situation, lack of sufficient nutrients would exacerbate and complicate the drought impact and occasionally it could influence the plant survival in case of very severe stress (Misra and Srivastava, 2000; Yadav and Bhathagar, 2001). Research suggest that if an appropriate mineral nutrition is selected, it could be obtained a relative high production in these conditions (Amiri et al, 2013).Silicon is one of the most frequent elements in soil, but as it is not placed in the vital element category for plant growth, it has not gained much attention to the biological role in the plant.

Considering that the country is placed on an arid and semi-arid region, it is important to consider the mineral nutrition of plants for growth increase as well as investigating the potential of mineral elements to overcome the environmental stress and it causes to expand development in agricultural and natural resources section; so, it makes possible to understand the silicon role in plant physiology, development of unique preparations to increase the plant resistance to unfavorable conditions.

LITERATURES REVIEW

Drought Stress

Drought stress with decreasing leaf area, stomata closure, reducing the protoplasmic activities and stabilizing carbon dioxide, decrease in protein synthesis and chlorophyll could cause to reduce the process of photosynthesis (Emam, 2004). Madder et al (1993) revealed that reducing the amount of storage photosynthesis materials on flowering time would increase the vulnerability of seed formation in Canola farm in case of drought stress. Of course, increase in amount of photosynthesis materials by limiting the competition between plants has not increased the seed formation in case of drought stress. They concluded that high level of photosynthesis materials storage is not merely enough to overcome the lack of photosynthesis materials or deficiency of reproductive tank (Madder, 1993). Results of carried out investigations showed by Ma et al (2006) showed that dealing the reproduction stage with drought stress will decrease most yield-dependent traits in Canola including number of pods in plant, weight of one thousand seeds and number of seed per pod which grain yield mainly occur by decreasing the number of pods and number of seed per pod.

Drought could result in production of harmful products including superoxide, hydrogen peroxide, hydroxyl radical, hydro-organic peroxides, singlet oxygen and perhydroxyl radicals which would imbalance the formation of reactive oxygen species (Tale Ahamd and

Haddad, 2010) which the amount of them must be controlled. Reactive oxygen species potentially have a capability that are reacted with many cellular components and they also cause to damage to the membrane and other critical macro molecular such as photosynthetic pigments, proteins, nucleic acids and lipids (Tale Ahmad and Haddad, 2010). According to the investigations, other stress often accompany the drought stress including reduction in available water for roots, increased evaporation and transpiration than water absorption, increase in cellular respiration and damage to the metabolic processes and cell structure, optical deterrent, photo oxidation and ultimately leaves death, increase in hardness of the soil resulted from drying and effect on root growth, reducing the growth of leaves and photosynthesis, non-availability of food in the root environment, accumulation of salts in the upper layers of soil and around the roots and poisoning nutrients (Kafi and MahdaviDamghani, 2007).

Increased understanding about salinity and drought effects on plants could decrease some salinity and drought-based damages. One of approaches to decrease the adverse effects of salinity and drought stress is to apply the proper mineral nutrition methods in plants which plays an important role in increase of yield. In this way, the role of elements such as silicon is used by some plant nutritionists (KhoshgoftarManesh, 2007).

Canola is more sensitive than dehydration during the vegetative and reproductive stages and it suggests the most sensitive particularly during the reproductive stage (Ghobadi, 2006). Canola`s depends on density, number of pod, number of seed per pod and weight of seed (Angadi, 2003). Hosseini et al (2007) during a survey about Canola found that irrigation effect on whole measured traits was significant.

Silicon

A collection of compounds which comprises silicon as their principal atom is referred silicon (Moradi et al, 2012). Silicon is the second frequent element on the Earth planet after followed by oxygen and it comprises 27.6% of lithosphere (Raven, 1983) as well as 1-45% of dry weight of soil (Sommer et al, 2006).The soil concentration of silicon is between 0.1 and 0.6 (Liang et al, 2003); also in plant, it comprises around 0.1 to 10% of the dry weight of the plant which is equal to some essential macro elements (Hodson et al, 2005). In spite of being frequent of this element on the land, due to accompanying with other elements it would be out of plant reach and plants are only able to use it as salicylic acid ($Si(OH)_4$). Silicon in plants is considered as a non-moving element which is not referred as an essential element and because of that there is not enough attention to the biological role of the plant (Tale Ahmad and Haddad, 2008); however, it is absorbed through roots and play substantial roles in plants (Khodabande Lou et al, 2013). There are many benefits related to silicon including resistance to living (e.g. pests and diseases) and non-living (drought, salinity, temperature and heavy metals) stress, increase in quality and quantity of agricultural productions (Richmond, 2003) and increase in phototropism and consequently increased photosynthesis (Khodabande Lou et al, 2013). Major mechanisms in which silicon decrease the metals stress include creating complex with metals, inhibition of metals transition from root to shoot, chambering of metal ions within the plant and stimulation of the antioxidant system in plants (Shi, 2005). Silicon in plants is an activating factor. Indeed, this element may act as a sign for activating the defense responses against the plant diseases. Also, silicon accelerates activating the peroxidase and PPO enzymes in the presence of fungal pathogens. Effect of silicon on plant yield is maybe due to its sedimentation in leaf width, increase in leaves strength and also increase in chlorophyll concentration on the leaf surface in which it would improve effective use of light by plant (Saadatmand and Enteshari, 2012). The use of soluble silicon to produce higher concentration of ribulosebiophosphat carboxylase is essential to adjust the carbon dioxide metabolism by this enzyme and as a result to increase the efficiency of carbon dioxide stabilization by plants and finally it would improve the photosynthesis in plant (Mohaghegh et al, 2010). Nevertheless, nowadays, understanding of importance of silicon for plant for plant growth and yield is eventually becoming better; so that silicon fertilizer are applied in order to increase the growth and sustainable production in different countries (Ma et al, 2006). Plant to defend against the reactive oxygen species have two enzymatic and non-enzymatic systems which could eliminate or neutralize free radicals. This enzymatic system includes super oxide dismutase, catalase, peroxidase, APX, glutathione peroxidase and glutathione reductase and non-enzymatic system consists ofascorbic acid, carotenoids, glutathione and tocopherol which keep the level of reactive oxygen species balanced in cell (AL-Aghabary, 2004). Silicon increases water use efficiency and offsets the drought stress effects as well as increasing the crop growth (Gao et al, 2006). Kaya et al. (2006) conducted an experiment on corn crop which showed that amount of calcium, potassium, dry weight, chlorophyll content and photosynthesis would decrease under drought stress conditions and silicon application in this condition leads to increase in these physiological parameters and then improves crop growth and production rate. Gong et al (2005) investigated the silicon effects on wheat under drought stress conditions. It suggested that silicon application in comparison with drought treatment,would increase antioxidant enzymes activities (superoxide dismutase, catalase and glutathione reductase). Under effect of drought stress, amount of hydrogen peroxide increased, while silicon decreasedhydrogen peroxide, phospholipase acid and damage resulted from oxidizing stress. Tale Ahmad and Haddad (2008) investigated silicon effect on resistance to wheat`s drought under greenhouse condition. Their results indicated that silicon treatment increased the activity of antioxidant enzymes and also improved the content of photosynthetic pigments and soluble protein in the leaves which had been under effect of drought stress; besides, silicon protected plant tissues against oxidizer attacks resulted from drought stress.Ahmad et al (2007) by investigating the silicon application effect on wheat growth under drought stress concluded that the use of silicon caused in increased crop biomass, plant height and spike weight on all water regime levels. Li et al. (2007) investigated the silicon effect on drought tolerance of corn under greenhouse condition. Results of experiment revealed that silicon could increase yield under drought stress conditions. In the silicon treatment, chlorophyll content and activity of antioxidant enzymes such as superoxide dismutase, catalase and peroxidase improved in comparison with control treatment; also, silicon increased plasma membrane permeability and photosynthesis rate.Also Khodabande Lou et al (2013) similarly investigated the reaction of common millet to drought stress and silicon application, and their results represented that water stress reduced seed yield by decreasing the number of ears per plant and decreasing the number of seed per ear; furthermore, silicon treatments improved seed yield.

MATERIALS AND METHODS

To study the effect of silicon spray on qualitative and quantitative characteristics of Canola under limit irrigation condition, some split plots in randomized complete blocks with four replications were designed and implemented to conduct this experiment in the Agricultural Research Station, University of Urmiaduring the agricultural year 2014-2015. Miyandoabcity is located in 46^o and 6` eastern longitude and 36$^o$ and 58` northern altitude and it is also located 1314 m above sea level. Experimental treatments including drought stress in two level e.g. normal irrigation (control) and drought stress considered as the major factors and then silicon spray on levels of 0, 1 and 1.5 mM considered as the minor factors. Drought stress was implemented by stopping irrigation in the final stages of reproductive growth (from producing pod to the physiological maturity). After preparation of farm, 42 kg of pure phosphorus from superphosphate resource and 12 kg pure potash as potassium acid for pre-planting and 12 kg pure nitrogen per hectare from nitrate ammonium resource (in three stages namely before planting, beginning time of shoot growth and emerging the first flower buds) were consumed for planting. Also, in order to combat against weeds, herbicide TREFLAN was used as pre-planting and then were mixed into fertilizer and soil by the light disc. After finishing above steps, preparing the plots with four meters long and two meter wide, and then planting operation with 32 cm row space on the fourth 4 cm on October 12, 2013.A two meter interval was considered between the plots to prevent water leakage into the plots. Additionally, the distance between two adjacent replication was measured 6 meters. The first irrigation for all treatments were applied immediately after the planting. Afterwards, furrow irrigation was performed based on the region`s weather. A Time Domain Reflectometry (TDR) was then used to measure the soil moisture and when soil moisture reached each of certain amount, irrigation was done by plot method. Silicon spray was carried out during three stages of plant growth (before the tillering, after the tillering and before the flowering). Sprays were applied at 4p.m in a clear and mild weather, so that leaves were fully soaked. On May 15, 2015 for final measurement, after removing the edge effect, four middle row were measured from each plot and then were used to measure their crop height, biological yield, grain yield, number of seed per pod, weight of each seed, chlorophyll a and b and the relative water content. To determine the seed yield, an area of 4.8 m^2 per experimental plot were individually separated and then keep under the free air for one week for final drying and reaching the 10% of humidity. Thereafter, after separating the seed from pods and seeds weight were calculated with an accurate scale and the seed yield were expressed in kg/ha under stress and non-stress conditions (Daneshmand et al, 2006). Data ANOVA related to the experimental traits and comparison of means were applied through Duncan multiple range test at the significance level of 5% using SAS 9.1 software. Moreover, Excel software were used to draw the diagrams.

RESULTS AND DISCUSSION

Drought Stress- Results of ANOVA indicated that effect of drought stress was significant on all the investigated traits (at the possibility level of 1%, tables 1-3). Generally speaking, drought stress decreased the plant height, biological yield, seed yield, measurement index, number of seed per pod, relative water content, chlorophyll a and b, total chlorophyll and ratio of chlorophyll a to b (tables 3-6).

As Lawlor et al (2002) suggested that water shortage could break down the chlorophyll, and glutamate as the precursor of chlorophyll and proline, were transformed into proline under the stress and finally it declined the chlorophyll content. Due to this reduction, plant growth decreases eventually and after that biomass (biological yield) and plant height reduces as well. On the other hand, reduction of storage photosynthesis materials during the flowering, it increases the vulnerability of seed formation under drought stress in Canola farm and finally the number of seed per ear would decrease under the drought stress.

The above results were in line with results obtained by Madder et al (1993) about reduction of number of seed under drought condition, results gained by Ma et al (2006) about reduction of number of pod and seed per pod, Tale Ahmad and Haddad (2008), Yadollahi et al. (2014a, b) and Tayebi et al. (2012) about reduction of growth and photosynthesis and Emam (2004) about reduction of chlorophyll and photosynthesis.

Silicon

Results of ANOVA showed that there was a significant relationship between silicon spray and all the examined traits (p-value 1%, tables 1-3). Silicon spray increased all the studied traits significantly except the ratio of chlorophyll a to b than control treatment.

There were significant differences in case of plant height, measurement index, relative water content, chlorophyll a and b and total chlorophyll in various concentration of silicon spray (1 and 1.5 mM) so that there were not any significant differences in case of biological yield, seed yield, number of seed per pod and the weight of one thousand seeds in 1 and 1.2 mM of silicon. Concerning the ratio of chlorophyll a to b, it could be expressed that use of silicon decreased this trait and there were meaningful differences in both case of 1 and 1.5 mM consumption (tables 4-6). As it was mentioned earlier, drought stress reduces plant`s yield by decreasing its chlorophyll, photosynthesis and finally the number of seed.

Silicon could improve plant ability to effectively use of light by increasing chlorophyll concentration per leaf area (Saadatmand and Enteshari, 2012). As a result, it leads to improvement of stabilization of carbon dioxide by plant and ultimately it improves plant`s photosynthesis (Mohaghegh et al, 2010). In this way, it prevents reduction of growth and plant`s yield due to the stress and then improves its drought tolerance.

The above results supported results of Gao et al (2006) about effect of silicon on increase in water consumption efficiency, adjusting the outcomes of drought stress and increase in plant growth, Kaya et al (2006) about application of silicon to increase the physiological parameters, plant growth and production rate, Ahmad et al (2007) about the effect of application of silicon on increasing plant biomass, height of plant and weight of wheat`s ear, Li et al (2007) about the effect of silicon on increasing the yield and chlorophyll content and results achieved by Khodabandeh Lou et al (2013) about improvement of seed yield.

Drought Stress * Silicon

Results of ANOVA indicated that there were significant correlation between drought stress and silicon spray and height of plant, biological yield, weight of one thousands seeds, relative water content, chlorophyll a and b, the ratio of chlorophyll a to b (tables 1-3). Results obtained from comparison of means (tables 4-6) showed that in both normal and under drought stress conditions, silicon spray increased all the studied traits significantly except the ratio of chlorophyll a to b; however, there were more difference between mean of traits on silicon consumption levels under drought stress compared to normal irrigation conditions. It could be concluded that in the current study, silicon suggests more offset effect. Also, in terms of most investigated traits, there were nosignificant difference between mean of traits when consuming 1.5 mM silicon under drought stress and mean of non-consumption of silicon under normal conditions. In other words, it could be resulted that under drought stress conditions, silicon spray with 1.5 mM on Canola could remarkably prevent reduction effects of drought stress. Also, under normal water conditions, silicon spray could improve agricultural and physiological traits which it results in improvement of yield in Canola crop.

Table 1 Results of ANOVA of investigated traits

Changes source	Degree of Freedom	Height of plant	Biological yield	Seed yield	Measurement index
Block	3	15.9293^{ns}	17552.78^{ns}	30209.38^{ns}	9.1102^{ns}
Drought stress	1	1935.0104**	723148.17**	1260875.04**	359.6082**
Silicon	2	574.0204**	265295.38**	148478.17**	4.0952**
Stress*silicon	2	105.5079**	18619.04*	18928.67^{ns}	9.4625^{ns}
Experiment error	15	15.5843	25451.91	11351.54	0.0063
R^2 (%)		4.11	5.28	5.37	0.12

Table 2 Continued results of ANOVA of investigated traits

Changes source	Degree of Freedom	Number of seed per pod	Weight of one thousand seeds	Relative water content
Block	3	2.2682^{ns}	0.0017^{ns}	6.0671^{ns}
Drought stress	1	81.7704**	1.4652**	1493.1038**
Silicon	2	42.8154**	1.8725**	601.9504**
Stress*silicon	2	3.3054^{ns}	0.0311**	148.2913**
Experiment error	15	0.8935	0.0427	12.7641
R^2 (%)		5.39	5.38	5.37

Table 3 Continued results of ANOVA of investigated traits

Changes source	Degree of Freedom	Chlorophyll a	Chlorophyll b	Ratio of a/b	Total chlorophyll
Block	3	0.0076^{ns}	0.0065	0.00331^{ns}	0.0259^{ns}
Drought stress	1	0.8588**	0.8513**	0.09400**	3.4202**
Silicon	2	0.2636**	0.2389**	0.02733**	0.9972**
Stress*silicon	2	0.0405**	0.0253**	0.00446**	0.1286**
Experiment error	15	0.0059	0.0036	0.00002	0.0185
R^2 (%)		5.49	5.64	0.32	5.54

Table 4 Results obtained from comparison of mean on considered treatments levels of investigated traits

		Height of plant	Biological yield	Seed yield	Measurement index
Drought stress					
	Normal irrigation	105.1^{a}	3196.6^{a}	2214.4^{a}	69.3^{a}
	Drought stress	87.1^{b}	2849.4^{b}	1756.0^{b}	61.5^{b}
Silicon					
	0	87.3^{c}	2819.4^{b}	1835.4^{b}	64.7^{c}
	1	96.7^{b}	3079.4^{a}	2018.6^{a}	65.4^{b}
	1.5	104.3^{a}	3170.3^{a}	2101.6^{a}	66.1^{a}
Stress*silicon					
Normal irrigation	0	100.5^{b}	3043.8^{b}	2120.8^{b}	69.7^{a}
	1	103.0^{b}	3207.8^{ab}	2220.0^{ab}	69.2^{b}
	1.5	111.8^{a}	3338.3^{a}	2302.5^{a}	68.9^{c}
Drought stress	0	74.2^{d}	2595.0^{c}	1550.0^{d}	59.7^{f}
	1	90.4^{c}	2951.0^{b}	1817.3^{c}	61.6^{e}
	1.5	96.7^{b}	3002.3^{b}	1900.8^{c}	63.3^{d}

Table5 Continuedresults obtained from comparison of mean on considered treatments levels of investigated traits

		Number of seed per pod	Weight of one thousand seeds	Relative water content
Drought stress				
	Normal irrigation	19.4^{a}	4.1^{a}	74.4^{a}
	Drought stress	15.7^{b}	3.6^{b}	58.6^{b}
Silicon				
	0	14.9^{b}	3.3^{b}	57.3^{c}
	1	18.6^{a}	4.1^{a}	67.8^{b}
	1.5	19.2^{a}	4.1^{a}	74.5^{a}
Stress*silicon				
Normal irrigation	0	16.4^{c}	3.6^{b}	69.8^{b}
	1	20.0^{b}	4.3^{a}	75.0^{ab}
	1.5	21.8^{a}	4.4^{a}	78.5^{a}
Drought stress	0	13.4^{d}	3.0^{c}	44.8^{d}
	1	17.1^{c}	3.9^{b}	60.7^{c}
	1.5	16.6^{c}	3.9^{b}	70.5^{b}

Table 6 Continuedresults obtained from comparison of mean on considered treatments levels of investigated traits

		Chlorophyll a	Chlorophyll b	Ratio of a/b	Total chlorophyll
Drought stress					
	Normal irrigation	1.586^{a}	1.247^{a}	1.275^{b}	2.833^{a}
	Drought stress	1.208^{b}	0.870^{b}	1.401^{a}	2.078^{b}
silicon					
	0	1.196^{c}	0.880^{c}	1.386^{a}	2.076^{c}
	1	1.444^{b}	1.070^{b}	1.356^{b}	2.514^{b}
	1.5	1.550^{a}	1.225^{a}	1.273^{c}	2.775^{a}
Stress*silicon					

Normal irrigation	0	1.468[b]	1.133[bc]	1.296[e]	2.600[c]
	1	1.595[a]	1.218[b]	1.310[d]	2.813[b]
	1.5	1.695[a]	1.390[a]	1.220[f]	3.085[a]
Drought stress	0	0.925[d]	0.628[e]	1.475[a]	1.553[e]
	1	1.293[c]	0.923[d]	1.401[b]	2.215[d]
	1.5	1.405[bc]	1.060[c]	1.326[c]	2.465[c]

CONCLUSION

In the present study, it was proved that drought stress reduced the investigated traits. Furthermore, silicon spray improved the investigated traits. There was a significant correlation between drought stress and silicon spray as well. By applying comparison of mean, it was observed that silicon spray compensated the effect of drought stress strikingly. On the other hand, under normal irrigation conditions, silicon spray affected the investigated traits positively. To sum up, it could be recommended using silicon as spraying in case of the Canola crop.

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