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RESEARCH PAPER

Studying the effect of bio-fertilizers on the yield components of Sesame (*Sesamum indicum*) genotypes under drought stress condition

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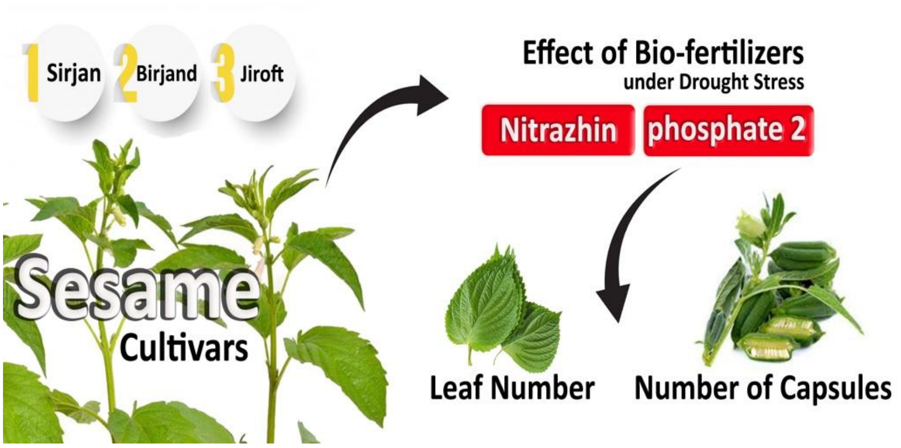
Highlights

- Drought stress causes damage to plants.
- Drought stress prevents the full performance of plants.
- Bio fertilizers are very effective in drought resistance of plants.
- Sesame is a good oil plant and is adapted to warm climates.

Graphical Abstract



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Abstract

Drought stress as the most important abiotic factor for limiting growth, adversely affects crop growth and production. In order to study the effect of bio-fertilizers on sesame genotypes yield under drought stress, an experiment was conducted based on split-split plots experiment in a randomized complete block design with three replications at the Agricultural Research Station, shahid Bahonar University. Treatments included as follow: irrigation base on water evaporation from pan with three levels (50, 90, and 130 mm) in the main plots and two types of fertilizers namely nitrazhin and phosphate 2 as two sub treatments and three cultivars: Sirjan, Birjand and Jiroft as sub-treatment randomly assigned to subplots The results showed that drought stress caused a significant reduction in the yield of capsules, number of seeds per capsule, biological yield, yield and oil content. The effect of fertilizer on leaf number was significant at 1% level and nitrazhin fertilizer had the greatest effect. There was a significant difference in the number of capsules or oil percent between varieties. The maximum performance (7.732 kg/ha) was due to primary stress (50 mm evaporation) and Sirjan cultivar. There is a significant interaction between fertilizer and stress and Nitrazhin fertilizer can reduce the effect of stress on the number of capsules.

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1. Introduction

As the most important abiotic factor for limiting growth, Drought stress adversely affects crop growth and production. Droughts affect photosynthesis through stomatal closure and not reach carbon dioxide to chloroplasts and decreasing in water potential of cells. Iran with an average precipitation of 240 ml has about one-third of the annual rainfall (700 mm), its climate is arid and Semi-arid. According to the average rate of population growth, It is estimated that the need for water increases to 2-fold every 35 years (Kumar et al., 2001). Application of bio-fertilizers particularly increased growth bacteria is the most important strategy for integrated management of plant nutrition for sustainable agricultural systems which is with enough inputs and a combination of biological and chemical fertilizers (Igiehon and Babalola, 2017). In recent years the approach to use these materials has increased and the attention of researchers for more conclusive research has focused on them in agricultural systems. The use of these fertilizers before, during and after environmental stress can make adjustments in plants and has increased the water-holding capacity of the soil, root growth and performance (Mitter et al., 2019). Bio-fertilizers contain preservatives with a dense population of beneficial soil microorganisms, or as some metabolic products are available which are used to improve soil fertility and adequate supply of nutrients required by the plant in a farming system (Kumar et al., 2001). Oilseeds have a special place due to supply human needs of food and industrial crops in between among the crops. Sesame plant with the scientific name of *Sesamum indicum* is the most important Species of Sesamum Genus and is a member of the pedaliaceae family and produces seeds that are used to produce edible oil. Countries such as India and China, Sudan, Burma, Thailand are major sesame-producing countries with about 60% of the total world production of sesame (De Araújo et al., 2017). The most practical part of sesame is seeds that have close to 75 percent fat and is composed of protein (Kenan et al., 2007). Sesame as an oilseed plant that is resistant to dehydration but in the seedling stage and during grain filling is sensitive to water deficit. (De Araújo et al., 2017) and (Kenan et al., 2007) showed that water restrictions will lead to a reduction in the growth and yield of sesame. Wright and colleagues 1995 found that water shortages could even halve the yield in the stage of growth because the sesame plant height is reduced (Wright et al., 1995). Sesame seed yield per unit area depends on the number of branches, number of capsules per plant, number of seeds per capsule and thousand seeds weight. Recent research indicates the importance of water deficit in Crops Production and Crop function will be changed due to the amount of water received at different developmental stages and usually decreases with increasing water stress (Khattab, 2007). Due to the roles of biological fertilizers on water stress, the current study was done to investigate the effect of bio-fertilizers on sesame cultivars in stress conditions (Guang et al., 2019).

2. Materials and Methods

This study was conducted in 2012 crop year at the Agricultural Research Station, Shahid Bahonar University of Kerman, located at 56 degrees 58 minutes east longitude and 30 degrees north latitude and altitude of 1754 meters above sea level on a land area of 800 square meters. Before the experiment, the soil was sampled, and some physical and chemical properties were analyzed (Table 1). The experiment was done by split-split plot design with three replications where the irrigation was carried out based on a water evaporation pan with 3 levels (50, 90, 130 mm) in the main plots. 2 types of fertilizer, Nitrazhin and phosphate 2 and *S. indicum* cultivars namely Jiroft, Sirjan, and Birjand as sub treatment were randomly put in the subplots. Seed spacing was 10 cm on the row. Each sub-plot consisted of three rows of length 2.8 meters, which distance was 40 cm between them and planting depth was 1 cm. The distance between plots was 0.5 meters. The main plot was divided into two sub-plots, and sub-plots were divided into three sub-sub plots. The biological fertilizer usage was according to the amount recommended by the manufacturers (half a liter per hectare). Land preparation operations were conducted in June. In order to prepare the land for planting, disk and leveling operations were performed. No herbicides, fungicides and pesticides were used during the period of land preparation and growing season. In June, the seeds planted in the basin on the row with 10 cm and between rows were 50 cm distance. Sesame seeds were immediately applied before planting by Bio-fertilizers with recommended and standard methods.

Table 1. Physical and chemical information of soil.

Absorbable potassium (mg/kg)	**Nitrogen (%)**			**Soil acidity (pH)**	**EC (dsm^{-1})**	**Percent of silt (%)**
436	0.045			7.69	2.4	26
Percent of sand (%)	Soluble cations(m/l)			Percent of clay (%)	soil pattern	Absorbable phosphorus
	Ca+	Na+	mg+			
35.6	20	29	12.5	38.4	Clay-loam	4.6

Seeds were sown at a depth of 1 cm. Methods were as follows: In the early morning, when the air was cold, and the amount of solar radiation was low, first seeds for bacterial inoculation was inoculated with special liquid material into regular nylon, and paper bag (to prevent sunlight) were blended, then were cultured. Soil moisture at planting was too good for the survival of bacteria. Seed inoculation operation was performed in an environment away from direct sunlight, and the time between inoculation and cultivation was possibly considered short. The first heavy irrigation was before planting so that the soil becomes wet at least to a depth of 1 m. Second, irrigation was immediately done to establish good bacteria and improve seedling emergence. The irrigation method was flooding with 8 days intervals. The last irrigation was performed 2 to 3 weeks before falling leaves during seed maturation. Irrigation was done every 8 days in plots from planting step till drought stress. Before flowering, drought stress was applied at three levels based on the evaporation pan (50, 90, and 130) mm in main plots. Due to the low growth rate in the early stages of sesame, the plant could not compete with weeds, and weed control is essential at this stage. During the entire growing season, weeding weeds was manually done several times by workers. To prevent seed loss in early November, when the new plant color was yellowish and capsules were inclined brown, Harvesting was done by hand.

At harvest time, each plot's two Lateral rows due to the marginal effect were not considered. In the middle rows, 20 plants (10 plants per row within a meter) were cut to measure the performance (grain weight) and were dried in the sun. To measure the characteristics before the final harvest, 5 plants from each plot were randomly selected and transferred to the laboratory, and traits such as number of capsules per plant, number of seeds per capsule, thousand seed weight, and total dry weight were measured. To evaluate the three rows' performance in each plot, two lateral rows and 0.5 mm were removed from above and below due to the marginal effect. The remaining plants were harvested to determine yield, and after placing the plant in the open air and in the shade to dry the seeds were separated from the straw. SAS and Excel software were used to do the Statistical analysis of experimental data; all averages were compared using Duncan's multiple range tests at the 5% level. After this, data were arranged in a split block Split. Interactions were investigated using software MSTATC, and Path analysis was performed with SAS software. Using indices of stress tolerance, tolerance of sesame were studied and affecting traits on performance under normal and stress conditions and using biological fertilizer was investigated and the contribution rate was determined.

3. Results and Discussion

3.1. Yield

The results of data analysis showed that irrigation had a significant effect on grain yield (Table 2). The highest yield was 683.56 kg/ha of the first level stress (control), and the lowest was 372.78 kg/ha from thirds of the surface stress (130 mm evaporation) (Tables 3, 4, 5). The highest yield was 732.7 kg per ha from the Sirjan cultivar related to the first level stress. The effect of water stress on plant growth and decreasing the grain filling period, reducing the number of heads per plant, and reducing the number of seeds has declined the yield. The results with the results (Selvaraj et al., 2020) were consistent. Biological fertilizers had no significant effect on yield. None of the double and triple interactions were significant. Hassan Zadeh and colleagues reported that increasing water stress decreases sesame yield. Drought stress decreased seed yield of sesame without any impacts on seeds (Singh et al., 2016).

Table 2. Results of variance analysis of stress, fertilizer, and cultivars.

S.O.V	df	NC	NSPC	SWT	Yield	Biomass	HI	TPDW	Oil
stress	2	9345.34 **	5052.92 **	4.22 *	475594.33 **	791115.12**	1.45 ns	51184.94 *	1044.96 **
fertilizer	1	12.51 ns	15.57 ns	0.006 ns	22991.37 ns	30722.69 ns	0.001 ns	1473.78 ns	40.9 ns
Stress* fertilizer	2	2208.27 *	141.79 ns	0.522 ns	31595.62 ns	14680.57 ns	0.526 ns	3812.54 ns	12.97 ns
cultivar	2	1105.4 *	5.57 ns	0.13 ns	2655.55 ns	6066.78 ns	0.46 ns	571.48 ns	465.57 **
Stress* cultivar	4	1013.82 *	116.32 ns	0.139 ns	6109.72 ns	1466.78 ns	0.12 ns	914.48 ns	116.26 ns
Cultivar* fertilizer	2	462.74 ns	10.01 ns	0.695 ns	14212.94 ns	8588.83 ns	0.25 ns	198.07 ns	34.57 ns
Stress* fertilize cultivar	4	76.87 ns	66.49 ns	0.217 ns	1674.48 ns	12684.77 ns	0.19 ns	1070.23 ns	18.04 ns
CV (%)	19.82	19.41	25.36	15.5	10.97	18.17	23.6	7.46	CV

*: significant at 5%, **: significant at 1%, ns: non-significant. (NC: Number of Capsules, NSPC: Number of Seeds Per Capsules, SWT: Seed Weight Thousand, HI: Harvesting Index, TPDW: Total Plant Dry Weight).

Table 3. Comparison of mean stress.

LS	NC	NSPC	SWT	Yield	Biomass	HI	TPDW	Oil
1	102.72 a	74.5 a	2.32 a	683.56 a	1287.87 a	2.41 a	270.47 a	52.83 a
2	76.5 b	63.33 b	2.28 a	610.79 a	1138.4 b	1.925 a	224 a	44.61 b
3	57.33 c	41.55 c	1.46 b	372.78 b	873.8 c	1.923 a	164.1 b	37.61 c

(LS: Level of Stress).

Table 4. Comparison of the results of biological fertilizer.

LBF	NC	NSPC	SWT	Yield	Biomass	HI	TPDW	Oil
1	79.35 a	60.30 a	2.03 a	576.34 a	1123.84 a	2.09 a	224.75 a	45.88 a
2	78.43 a	59.25 a	2.01 a	535.07 a	1076.13 a	2.08 a	214.30 a	44.14 a

(LBF: Level of Biological Fertilizer).

Table 5. Comparison of the mean cultivar.

LC	NC	NSPC	SWT	Yield	Biomass	HI	TPDW	Oil
1	79.11 ab	60.22 a	2.01 a	550.37 a	1084.17 a	2.03 a	215.92 a	43.94 b
2	70.88 b	60 a	2.11 a	547.15 a	1095.68 a	2.11 a	226.02 a	50.55 a
3	86.55 a	59.16 a	1.94 a	569.61 a	1120.12 a	2.11 a	216.64 a	40.44 b

(LC: Level of Cultivar).

3.2. Number of capsules

The results showed that irrigation had a significant effect on the number of capsules per plant (Table 2). The maximum number of capsules was 102.72 per unit of plant related to the first level of stress (control), and the lowest was 57.33 on the third level of stress (130 mm evaporation). The third level of stress decreased 44.21% in the number of capsules (Table 3). Drought reduced the number of capsules per plant by decreasing the growth period and also accelerating flowering. Biological fertilizer had no significant effect on the number of capsules per plant. Significant differences among cultivars were observed in the number of capsules per plant, the maximum number of capsules was 86.55the related to Sirjan cultivar, and the lowest was 70.88 from the cultivar Birjand (Table 5). The interaction of stress and stress in the amount of fertilizer in the cultivar on the number of capsules per plant was significant. Cultivars vary in terms of biological fertilizer, irrigation, and the number of capsules showing significant differences. Ramirez and Kelly expressed that drought stress reduced the number of pods per plant in comparison with the normal condition (Ramirez and Kelly, 1998).

3.3. Number of seeds per capsules

The number of seeds per capsule was affected by irrigation (Table 2). The highest number of seeds per capsule was 74.5 due to stress level one (control), and the lowest was 41.55 due to the third stress level (130 mm). The number of seeds per capsule in the third stress level to the first level stress was 44.22% (Table 3). Decreased plant growth period and reduced stress during the grain-filling period declined the number of grains per head. The biological fertilizer effect on grain number was not significant. Significant differences among cultivars were observed in the number of grains per head. The highest number of seeds per capsule was 60.22, related to the Jiroft cultivar (Table 5). There were no significant interactions between double and triple the number of seeds per capsule.

3.4. Seed weight thousand

The results of data analysis showed that the effect of irrigation on thousand Seed weight was significant at the five percent level (Table 2). The highest Seed weight was 2.32 g related to the first stress level (control), and the lowest was 1.46 g due to third level stress (Table 3). Drought stress reduced thousand Seed weight with decreasing in the growth period and the grain-filling period. Increasing thousand seed weight is related to environmental conditions during grain filling. Moisture loss at this time will result in reduced thousand seed weight. The reason for this decrease is probably due to limited retransmission among drought treatments. (Doran, 2002) also reported that reducing the irrigation intervals increased the thousand seed weight Biological fertilizer had no significant effect on Seed weight. The biological fertilizers usage increased remobilization and thousand Seed weight due to an increase in root development and nutrient uptake. A significant difference wasn't observed among cultivars in thousand Seed weight. The highest Seed weight was 2.11 g, related to the Birjand cultivar (Table 5). There wasn't significant double and triple interaction on thousand Seed weight.

3.5. Total plant dry weight

Data analysis results showed that stress had no significant effect on plant dry weight at 5% level (Table 2). The maximum dry weight was 270.47 g related to first-level stress (control). The lowest dry weight was 164.1 g, related to tertiary level stress (130 mm evaporation) (Table 3). Reducing irrigation decreased the grain filling duration. In order to escape from stress, the stages of the development will be faster, so remobilization of photosynthesis products to seeds and plant dry weight will be decreased. The effect of bio-fertilizer on plant dry weight was not significant. There were no significant differences among cultivars in dry weight most of the dry weight-related to Birjand cultivar (Table 5). The interaction between cultivar and stress, stress and manure, fertilizers and cultivar, and the amount of stress on plant dry weight was not significant (Table 2).

3.6. Biomass

Data analysis results showed that the impacts of drought stress on biomass were significant at a one percent level (Table 2). Mean comparisons showed that biological yield was 1138.4 kg/ha and the lowest was 873.8 kg/ha, related to second and first stress levels, respectively (Table 3). Drought stress (third level) decreased 23.24% of biological function. Because drought stress affects the hormones that regulate growth and reduce these hormones (gibberellin and cytokinin), it will decrease the cell division process and reduce the number of leaves, leaf area, internodes distances, and ultimately reduces the weight and dry weight of biomass. Biological fertilizer effects on biomass were not significant. Cultivars showed no significant differences in biological function. The highest Biological yield was 1095.68 kg related to Birjand cultivar, and the lowest was 1120.12 kg from of Sirjan cultivar (Table 5). None of the double and triple interactions was significant.

3.7. Harvesting index

Irrigation had no significant effect on the harvest index (Table 2). Biological fertilizers have no significant effect on the harvest index. Irrigation has no significant effects on harvest index and seed yield because the effect of irrigation on biomass and grain yield was the same. There were no significant differences among cultivars in the Harvest index. Despite the significant effect of irrigation on the Harvest index, the maximum harvest index was 2.41% on the first level of stress (control) (Table 3). According to the formula (HI), Yield loss due to drought reduced harvest index. Some investigators reported that the harvest index reduced under water deficit conditions (Wright et al., 1995). It was observed in beans that if drought occurs during vegetative growth, the harvest index increases. The effect of drought on crop drought stress applied at extreme levels significantly increased harvest index compared to the control treatment and other stress levels (Singh et al., 2016).

3.8. The oil percent

Oil content was affected by irrigation (Table 2). The highest oil content was 52.83, related to the stress level I (control), and the lowest was 37.61 of the third stress level (130 mm). The impacts of Biological fertilizers on oil content were not significant. No significant differences were observed between cultivars in oil. Most of the oil from the Birjand cultivar was related to the first level of stress (stress control), and the lowest percentage of oil in the third level of stress was related to the Jiroft cultivar (Table 5). Interactions between double and triple the oil were not significant. Moreover, there's a significant positive correlation between seed weight and the amount of oil. Kumar and colleagues studied the effect of irrigation on the growth and yield of sesame and reported that irrigation increases leaf area, the number of capsules plant, seed weight, oil yield on 30 and 60 days after planting (Kumar et al., 2001). The Results of comparison Interaction of stress and cultivar, shown in Table 6.

Table 6. Results of comparison Interaction of stress and cultivar.

LS	LC	NC	NSPC	SWT	Yield	Biomass	HI	TPDW	Oil
1	1	101 b	76.66 a	2.46 a	675.3 ab	1289 ab	1.91 bc	255.5 a	53 b
1	2	81.50 bc	72.5 ab	2.44 a	642.7 ab	1269 ab	2.06 abc	289.2 a	58 a
1	3	125.7 a	74.33 ab	2.07 abc	732.7 a	1306 a	1.78 c	266.7 a	47.5 cd
2	1	82 bc	67 ab	2.27 ab	592.8 b	1122 b	1.9 bc	221.1 ab	44.33 de
2	2	74 cd	64.5 ab	2.3 ab	628.6 ab	1136 ab	1.84 c	232.2 ab	50.16 bc
2	3	73.5 cd	58.5 bc	2.26 ab	611 ab	1158 ab	2.02 abc	218.7 ab	39.33 f
3	1	54.33 d	37 d	1.31 d	382.9 c	841.8 c	2.27 abc	171.2 b	34.5 g
3	2	57.2 d	43 cd	1.58 bcd	370.2 c	882.9 c	2.43 ab	156.7 b	43.5 e
3	3	60.5 cd	44.66 cd	1.49 cd	365.2 c	896.6 c	2.54 a	164.5 b	34.83 g

4. Conclusion

The results showed that drought stress can have significant effects on plant morphological traits, which has the greatest impact on plant yield. The results of this study showed that biological fertilizers can neutralize the effects of stress by affecting the development and growth of various plant organs such as roots. In this study, the interaction of stress and fertilizer was significant that nitrogen fertilizer had the greatest effect in reducing the effect of stress. In this study, the highest grain yield was related to Jiroft genotype and showed that this genotype is more resistant to drought than other genotypes.

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