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Annals of Agricultural Science, Moshtohor (ASSJM)
https://assjm.journals.ekb.eg/

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Original Article Vol. 61(3) (2023), 681 –694 DOI:10.21608/ASSJM.2024.245537.1252

Effect of Foliar Application with Putrescine and Benzyladenine on Vegetative Growth, Yield and Its Components and Seed Oil Contents of Chia (*Salvia Hispanica* L.) Plants Grown under Water Stress Conditions

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Abstract

This work aimed to investigate the effects of foliar application with putrescine (0, 25, 50 ppm) and benzyladenine (0, 50, 100 ppm) on growth performance, yield parameters, seed oil percentage and fatty acids composition of chia (*Salvia hispanica* L.) plants grown under water stress conditions (40, 70% Evaporation Transpiration rate (ETo) and 100% ETo full irrigation as control). The results showed that, both of the two water deficit irrigation levels 70 and 40% ETo significantly decreased all studied growth and yield parameters of chia plants in both seasons as well as, these water stress levels decrease seed oil percentage and unsaturated fatty acids such as linolenic and Linoleic of chia plants compared with unstressed plants (control 100% ETo). In contrast, the two water stress levels induced a marked increase water use efficiency (WUE) and saturated fatty acids compared with unstressed plants (100% ETo). In addition, the foliar application treatments of putrescine at 25 ppm and benzyl adenine at 50 ppm alone or in combination with the two water stress levels significantly increased all the above mentioned traits of growth, yield parameters and WUE in both seasons as well as seed oil percentage and unsaturated fatty acids composition in second season. Since, putrescine at 25 ppm was the most effective treatment in this respect. Generally, the foliar application treatments with low concentration of putrescine and benzyl adenine were the most effective treatments for improving growth, productivity, seed oil percentage, and fatty acids composition of chia (*Salvia hispanica* L.) plants under normal or water stress conditions.

Keywords: *Salvia hispanica* L., Unsaturated fatty acid, putrescine (Put), benzyladenine (BA), Water use efficiency, ETo

Introduction

The annual herbaceous plant known as chia (*Salvia hispanica L.)* belongs to the Lamiaceae family of mints **(Yeboah *et al.*, 2014 and Silva *et al.*, 2016).** Chia is mostly grown for its seeds, which produce tiny, hermaphrodite, white and purple blossoms that measure 2-4 mm. Its leaves are 4–8 cm long and 3–5 cm wide, with a serrated, reverse petiolate appearance. It has a maximum height of one meter. Chia seeds are usually small, oval-shaped seeds. A seed's hue might vary from white to black to grey. According to **Grancieri *et al.*, 2019, Das 2018, and Knez Hrnčič *et al.*, 2018,** the plant is light-sensitive. Chia is native to northern Guatemala and southern Mexico **(Yeboah *et al.*, 2014 and Silva *et al.*, 2016).**The strong nutritional and therapeutic properties of chia seeds, their use has increased dramatically in recent years **(Knez Hrnčič *et al.*, 2020).** Proteomics (15–25%), lipids (30–33%), carbohydrates (26-41%), high dietary fiber (18–30%), minerals (calcium, phosphorus, potassium, magnesium), vitamins (A, B, K, E, and D), and antioxidants are all present in chia seeds. Omega-3 fatty acid linolenic acid and omega-6 fatty acid linoleic acid are polyunsaturated fatty acids that make up the majority of chia oil **(Silva *et al.*, 2016).** Antioxidants included in chia seeds are believed to provide heart and liver protecting properties, anti-aging and anti-carcinogenic properties, and cardiovascular disease prevention properties. They therefore offer the feed, food, pharmaceutical, medical, and neutraceutical industries a lot of potential for the future **(Ullah *et al.*, 2016).** In Egypt, the primary constraint limiting agricultural production in recent times has been the scarcity of irrigation water. Lowering irrigation water levels and conserving irrigation water in recently planted soils is a crucial first stage in Egypt's strategy. Accordingly, one of the main goals of many recent agricultural studies has been the development of crop tolerance to water scarcity **(Cantale *et al.*, 2018).**

Future species may need to be chosen based on their low water requirements due to predicted climatic changes **(Herman *et al*., 2016).** In dry and semi-arid locations, water deficiency stress is thought to be the most restrictive environmental factors on the growth and production of many plant species according to **Fathi and Tari (2016)**, plants are impacted by water scarcity stress on a morphological, physiological, biochemical, and molecular level **(Fathi and Tari 2016).** Drought inhibits or slows down the elongation of the shoots, reduces the size of the leaf blade, limits cell division, and considerably lowers stomatal conductance, which affects the uptake and transport of ions, water, and gas exchange **(Farooq *et al.*, 2009).** Reactive oxygen species (ROS) are produced during drought stress, which oxidatively damages plant cellular components **(Asada, 2006).** These organisms cause photo inhibition, oxidative damage, and disruptions to proteins, lipids, and nucleic acids, all of which result in cellular death. They also change the activity of enzymes. **(Hasanuzzaman *et al.*, 2020 and Gill and Tuteja 2010).** An intriguing choice is *Salvia hispanica* L., sometimes known as chia, which is said to be resistant to drought and still grow well when there is less water available. Water availability was found to have a major impact on WUE in biomass yield and production. Lastly, when water availability dropped, the WUE and oil output rose. According to **(Herman *et al.*, 2016),** these findings demonstrate that while chia is highly sensitive to water deficiency, it can compensate by increasing its yield, lipid content, and omega-3 content. WUE for biomass and yield is also shown to be a constant number. Furthermore, **Jamshidi *et al.*, (2020)** showed that the chia plant's total biomass, plant height, accessory branches, node count, and ultimate leaf area all decreased with increasing drought stress. Regarding the general tendency of chia plants to develop more slowly and exhibit a reduction in physiological properties when subjected to extreme water stress or drought stress. Growth regulators are substances used to enhance the tolerance of plants to abiotic stresses and increase plant growth and yield. In addition, many substances, including putrescine and benzyl adenine, have been used to reduce the negative effects of water stress (**Gupta *et al.*, 2012**).

Putrescine belongs to a family of compounds called polyamines, which are thought to act as regulators of plant growth. All biological things contain these low molecular weight nitrogenous molecules **(Skowron and Trojak 2021).** In a previous work, **Mohammadi *et al.*, (2018)** demonstrated that putrescine (Put) prevented the accumulation of drought-induced reactive oxygen species (ROS) by enhancing antioxidants enzyme activity. Similar research demonstrated that polyamines enhanced the system's defense against oxidative stress, functioned as components of the stress-signaling system, and controlled the production of proteins, nucleotide triphosphates, RNA, DNA, and macromolecule protection **(Kuznetsov and Shevyakova, 2007and Li *et al.*, 2018**). According to **Fouad *et al.*, (2018),** using putrescine (10 ppm) foliar-spray to *Salvia hispanic* produced the best herbage fresh and dry weights as well as increased seed yield at 100% ETO. Furthermore, **Mabudi Bilasvar *et al.*, (2022)** worked on rapeseed plants found that put treatment lengthened the seed filling time, especially under limited irrigations, which boosted the oil content of seeds. Nevertheless, by decreasing oleic acid and increasing the levels of linoleic and linolenic acids, Put treatment under high water stress improved the unsaturation index.

According to **Zara and Karimi (2023**), phytohormones such as cytokinin are essential for plants to be able to with stand the effects of drought, by lowering the oxidation of unsaturated fatty acids, they shield cell membranes from deterioration and help plants withstand drought. Furthermore, cytokinins prevent the production of free radicals that would otherwise damage membrane lipids, such as superoxide (O^2) and hydroxy radical (OH^-), and they also accelerate their breakdown **(Werner and Schmulling 2009)**. According to **El-Metwally *et al.*, (2021)** research on soybean plants, benzyladenine at a dose of 150 mg L^{-1} may be utilized to offset the loss in seed yield resulting from reducing irrigation water supply to 80% of crop evapotranspiration (while conserving 20% of irrigation water). Irrigation water use efficiency progressively increased with lower irrigation water use and a greater benzyladenine rate. Additionally, **Khosravi-Nejad *et al.*, (2022)** observed that under drought stress, the plant growth hormones, particularly CK., changed the fatty acid profile, showing an increase in polyunsaturated and monounsaturated fatty acids. The purpose of this study was to establish the impacts of foliar application of putrescine and benzyl adenine as well as varying levels of water stress (40, 70 % of ETO) on the vegetative development, yield, and constituents of chia (*Salvia hispanica L*) plants, as well as the contents of their seeds.

Materials and Methods

Two field experiments were carried out at the Experimental Farm Station of the Faculty of Agriculture Moshtohor, Benha University, Qalubia Gavernorate, Egypt, during two seasons of 2020/2021 and 2022/2023 to investigate the effects of putrescine (Put.) and benzyladenine (BA) on growth, yield and seed oil contents of chia plants grown under two water stress levels i.e., 40, 70 and 100% of ETo (Evapotranspiration) as control.

The seed of chia plants were obtained from Experimental farm of Floriculuture of Faculty of Agriculture, Moshtohor, Benha University. Seeds of chia were sown on 14th October in the first and second seasons. 10 seeds / hill were sown in 1 cm deep on one side of the ridge at 30 cm apart. The soil was prepared on 20 September for both seasons and divided into three main plots for three water irrigation levels. Water was applied continuously in the sown row until complete germination (20 days from sowing).

The seedlings were thinned to two seedlings / per hill (drip) after 25 days from sowing. All plots were fertilized with the rate of 200kg/fed of calcium superphosphate (15.5% P_2O_5) which was added during soil preparation. Also, all plants were fertilized with ammonium sulfate (20.6 % N) and potassium sulfate (48 % K_2O) at the rate of 200 kg /fed added in irrigation water which were divided into two equal doses after 35 and 65 days from sowing in both seasons.

The experiment treatments were as follows:

This experiment included 15 treatments, which were the combination between three water irrigation levels and five treatments of putrescine and benzyladenine as follows:

a) Water irrigation levels:

Drip irrigation system was used to apply the levels of water irrigation in the experiment. Three irrigation levels supply were used i.e., 100% (control) of ETo, 70% of ETo and 40% of ETo, respectively of water levels of the reference evapotranspiration (ETo) by the Penman-Monteith method **(Allen *et al.*, 2006)**. The irrigation treatments were started after 30 days from sowing and irrigation treatments were applied every ten days (10 days intervals) at a rate with discharge of 4 L/h for 100% water irrigation level and the added water volumes were calculated for each water level. Water irrigation levels and irrigation water volume applied m^3/fed (i.e., 100 % of ETo (control) irrigation with 855, 96 m^3 water/fed, 70 % of ETo irrigation with 599.17 m^3 water/fed and 40% of ETo irrigation with 342.38 m^3 water/fed, respectively of chia plants in both seasons.

Table 1. Monthly average of metrological data of the experimental farm of faculty of agriculture Moshtohor, Benha University, Qalubia Governorate during 2020-2021and 2022-2023 seasons.

Metrological data										
Air temperature (^{o}C)										
Month	Max.		Min.		Average		R.H. (%)		ETo (mm/day)	
	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
October	34.83	31.89	19.89	18.75	27.36	25.32	57.79	57.15	4.85	3.55
November	25.94	26.38	14.92	14.59	20.43	20.48	63.72	60.14	3.01	2.74
December	23.63	24.20	11.25	12.39	19.27	18.29	61.67	64.43	2.50	2.08
January	22.29	21.84	9.27	9.42	15.78	15.63	62.66	65.39	2.32	2.25
February	22.54	20.90	9.13	7.93	15.83	14.41	64.91	60.45	3.15	3.21
March	23.98	27.51	9.87	12.44	16.92	19.97	63.94	47.27	3.74	3.63

b) The applied treatments:

Bioregulators putrescine (Put.) and benzyladenine (BA) were used as foliar application as follows: Control (Tap water) 0.0, Putrescine (Put.) at 25 and 50 ppm, Benzyladenine (BA) at 50 and 100 ppm. Plants were sprayed with putrescine and benzyl adenine using atomizer three times at 30, 45, 60 days from sowing.

The treatments were arranged in split plot design with five replicates; the main plots were assigned to water irrigation levels each main plot contains five dripper lines (5 rows of 25m length and 4m width spacing).While five treatments of putrescine and benzyl adenine were located in subplots.

Sampling and collecting data:

1. Vegetative growth characteristics:

Six plants of chia from each treatment were randomly taken at 80 days after sowing to measure plant growth characteristics (i.e., plant height, number of branches, number of leaves, leaf area, dry weight of stems and dry weight of leaves /plant). The samples of the above ground vegetative parts were dried in the oven for 48 h in 75°C to a constant weight and then the dry weight per plant was calculated.

2. Yield and its components:

At harvest date (150 days after sowing) six randomly plants from each treatment were taken from the middle rows to determine yield characters [i.e., main inflorescences length (cm), number of inflorescences /plant, seeds yield (g)/plant and Weight of 1000 seeds (g)].

3. Determination of water use efficiency (WUE):

Water use efficiency (WUE) was calculated according to **Guang-Cheng *et al.*, (2008). WUE** = Seed yield (Kg ha^{-1}) / Water applied (m^{3}ha^{-1}).

4. Determination of seed oil contents of chia plant:

A. Determination of Crude Fat according to the method described by **A.O.A.C. (1990).**

B. Determination of Fatty acids: Fatty acids determination of oil was extracted by hexane and were analyzed by Agilent HP6890 capillary gas chromatography and reported in relative area percentages .The methyl esters of fatty acids were prepared according to the method of **Glass (1971).**

Statistical analysis:

Data obtained in this study were statistically analyzed by the methods described by **Snedecor and Cochran (1989)**. Using the MSTAT-C Statistical software package **(Michigan state university, 1983).**

Results and discussion

1. Growth parameters of chia plants:

As for the effect of deficit irrigation treatments, data in **Table (2)** show that all tested growth parameters of chia plants (i.e., plant height, number of branches, number of leaves, leaf area, and dry weight of stems and leaves /plant) were significantly decreased with decreasing water irrigation levels from 70% to 40% ETo compared to the control plants (Full irrigation level at 100% ETo) at 80 days after sowing in the two growing seasons of the experimental study. The highest reduction values of the previous growth parameters were observed with 40% ETo water irrigation level in both seasons.

Meanwhile, water irrigation level at 100% ETo was the most effective treatment which gave the greatest mean values of the above mentioned growth parameters of chia plants in both seasons.

Our results related to the effect of deficit irrigation treatments are in accordance with those of **Alishah *et al.*, (2006)** indicated that water deficit stress reduces plant growth by reducing cell turgor and relative water content (RWC), which in turn decreases cell elongation and development, consequently reducing leaf area, and an imbalance between antioxidant defenses and the amount of reactive oxygen species (ROS) leads to oxidative stress under water deficit conditions. These results are in agreement with those reported by (**Khakdan *et al.*, 2016, Lovelli *et al.*, 2019, Jamshidi *et al.*, (2020) and Kalamartzis *et al*.**, **2020).**

With regard to the effect of foliar application treatments, also data in **Table (2)** shows clearly that foliar application treatments with two concentrations of both putrescine and benzyladenine significantly increased all previous studied growth parameters (i.e., plant height, number of branches, number of leaves, leaf area, and dry weight of stems and leaves /plant) at 80 days after sowing in both seasons compared with the untreated plants (control). In this respect, foliar spraying with putrescine at 25 ppm followed by benzyladenine at 50 ppm resulted in the highest mean values of the pervious growth parameter when compared with control and other treatments application during both seasons.

Such increment in all studied growth parameters in putrescine treated chia plants may be attributed to the main role of Put. as a direct effect on cell division and growth followed by differentiation, so that cell division and growth effects on the morphological and physiological characteristics of the plant and lead to increase in vegetative characteristics. With the increase in the vegetative characteristics, the active photosynthesis with stimulation of protein synthesis, and metabolism of nitrogen components, the percentage of leaves dry material also increased **(Ozturk and Demir 2003, Talaat *et al.*, 2005 and Mahgoub *et al.*, 2011)**. Moreover, similar results were obtained by **Fouad *et al.*, (2018)** found that foliar-spray application of putrescine (10 ppm) on chia plant increased the optimum fresh and dry weights of herbage and roots under water irrigation levels at 100% ETO. Also, **Singh and Bala (2018)** and **Gabrel *et al.*, (2018)** on chrysanthemum plant indicated that using benzyl adenine at 100–200 ppm led to significant increases of some studied parameters (branch dry weight, period from showing color to full opening stage, flowering duration on plant and inflorescence dry weight.

Concerning, the interaction effects between deficit irrigation water treatments and foliar applications with either putrescine or benzyl adenine treatments were significantly increased on all tested growth parameters **(Table 2)** at 80 days after sowing during both seasons. Since, the highest mean values of tested growth parameters of chia plants were obtained from the interactive treatments of the water irrigation levels at 70 and 40% ETo and foliar application with putrescine at 25 ppm and benzyladenine at 50 ppm followed by the irrigation levels at 70 and 40% ETo and putrescine 50 ppm and benzyladenine 100 ppm compared with untreated plants (control) during the two growing seasons.

These results are in harmony with the results obtained by **Khodabakhshi *et al.*, (2023)** indicated that putrescine reduced the adverse effects of drought stress on the fresh and dry weight of shoots, leaf area and dry matter. In general, foliar spraying of indigo plants with 0.5 mM putrescine improved the vegetative state of indigo plants by improving the antioxidant system against oxidative stress, especially under the moderate and severe drought stress conditions. Also, **Liu *et al.*, (2020)** mentioned that cytokinins have a significant role in plant tolerance to stress as well as promoting plant growth and development under normal plant growth conditions.

2. Yield and its components of chia plants:

As for the effect of deficit irrigation treatments, data in **Table (3)** indicate that different water stress levels 70 and 40% of ETo significantly decreased yield parameters such as main inflorescences length, number of inflorescences, seed yield and Weight of 1000 seed of chia plants comparing with full irrigation level (100%) control during both seasons. Also, the lowest water irrigation level at 40% of ETo was the most effective treatment which gave the highest reduction in abovementioned yield parameters compared with the control plants in both seasons.

Meanwhile, water irrigation level at 100% ETo was the most effective treatment which gave the greatest mean values of the previously mentioned yield parameters in both seasons.

These findings are in harmony with those obtained by **Raza *et al.*, (2014)** on wheat, **Mahdavi Khorami *et al.*, (2020)** on Sesame and **Danping *et al.*, (2021)** on rice. In addition, **Harisha *et al.*, (2023)** showed that deficit irrigation at severe led to reductions in seed yield in chia plant.

Regarding the effect of applied treatments, data in **Table (3)** clearly indicate that all applied treatments with two concentrations of both putrescine and benzyladenine significantly increased yield traits (i.e., main inflorescences length, number of inflorescences, seed yield and Weight of 1000 seed) when compared with the control during both seasons, while putrescine at 25 ppm gave the highest values of the abovementioed yield parameters followed by benzyladenine at 50 ppm when compared with the control and other treatments during the both seasons.

These results are in agreement with previous results reported by **Liu *et al.*, (2016)** on wheat, **Fouad *et al.*, (2018)** on chia and **Hussein *et al.*, (2023)** on wheat.

Concerning, the interaction effect between deficit irrigation water treatments and foliar applications with either putrescine or benzyl adenine treatments significantly increased yield characteristics **(Table 3)** in both seasons. Since, it could be noticed that the highest increase of yield characteristics were existed with putrescine at 25 ppm followed by benzyladenine at 50 ppm under water irrigation levels at 70 and 40% of ETo when compared with untreated plants and other treatments in the both seasons.

In this regard, these results are in agreement with those obtained by**, Gholami *et al.*, (2013)** on basil, **Ghassemi – Golezani *et al.*, (2019)** on rapeseed, **El-Metwally *et al.*, (2021)** on soybean and **Wasaya *et al.*, (2023)** on wheat. Also **Farzi-Aminabad *et al.*, (2021)** on safflower revealed that foliar sprays of growth regulators, particularly putrescine, increased grains per plant, grain yield, and harvest index, leading to an improvement in oil yield per unit area under different levels of water supply.

3. Water use efficiency (WUE):

Regarding the effect of deficit irrigation treatments, the presented data in **Table (3)** indicate that different water stress levels 70 and 40% of ETo significantly increased water use efficiency (WUE) compared with full irrigation level (100%) control during both seasons.

These results are in agreement with those of **Herman *et al.*, (2016), Silva *et al.*, (2016)** and **Lovelli *et al.*, (2019)** on chia plants which indicated that water use efficiency increased with water availability and was higher in the P genotype at all irrigation levels.

As for the effect of applied treatments, data in **Table (3)** show that all applied treatments with two concentrations of both putrescine and benzyladenine significantly increased water use efficiency (WUE) when compared with the control during both seasons. Putrescine at 25 ppm gave the highest values of WUE followed by benzyladenine at 50 ppm when compared with the control and other treatments in both seasons.

Similar results were obtained by **Liu *et al.*, (2018)** who showed that treating *Santalum album* L. plants with BA at 1 mg L^{-1} significantly increased the accumulation of water use efficiency.

Concerning the interaction effect between different foliar spray treatments and different water levels in **Table (3)** indicated that the highest values of water use efficiency (WUE) were obtained by 40 % ETo water irrigation level with different applied treatments, it reached the maximum with 40 % ETo water irrigation level and putrescine 25 ppm followed by 40 % ETo water stress level and BA 50 ppm. The values of water use efficiency (WUE) decreased gradually with 70% ETo water irrigation level with different applied treatments and it reached the lowest value with control.

In this respect, these results could be explained by **Fathi Amirkhiz *et al.*, (2021)** found that foliar spraying of polyamine compounds can increase seed and oil yields and water use efficiency while also enhancing the quality of safflower oil under deficit irrigation conditions. Also, **El-Metwally *et al.*, (2021)** on soybean indicated that irrigation water use efficiency progressively increased with decreasing irrigation water amount and increasing benzyladenine concentration treatment.

4. Oil percentage:

It is clear from data in **Table (3)** that different water stress levels 70 and 40% of ETo decreased the oil percentage comparing with full irrigation level (100%) control during 2022 season. Also, the lowest water irrigation level at 40% of ETo was the most effective treatment which gave the highest reduction in oil percentage followed by 70% ETo. Since, water irrigation level at 100% ETo recorded the greatest mean values of oil percentage in second season.

These results are in agreement with those obtained by **Sharafzadeh and Zare (2011)** showed that drought stress increases the percentage of essential oils in various Lamiaceae family medicinal plants while lowering shoot biomass, which lowers the amount of essential oils present. In addition, **Harisha *et al.*, (2023)** showed that deficit irrigation at 25, 50 and 75% ETo led to reductions in oil yield and in omega–3 yield in chia plant.

As for the effect of applied treatments, data in the same Table point to that, all of foliar application treatments increased the oil percentage in second season. Putrescine at 25 ppm gave the highest values of oil percentage followed by benzyladenine at 50 ppm when compared with the control and other treatments in second season.

Similar results were reported by **Faraji *et al.*, (2015)** showed that putrescine had a significant effect on essential oil efficiency, percentage, yield and composition of *Satureja hortensis*. Also, **Jabbar and Hamza (2021)** on sweet bean plant indicated that the highest average oil content was obtained with foliar application of benzyladenine at 2.5 mg L^{-1} when compared to the control treatment.

As for the effect of interaction, data in **Table (3)** clearly indicate that all the interactions effect between water stress levels and applied treatments increased the oil percentage in seeds of chia plants in second season. Also, putrescine at 25 ppm and benzyladenine at 50 ppm gave the highest oil percentage in seeds of chia plants under water stress levels at 70 and 40% of evapotranspiration (ETo) compared with untreated plants in second season.

These results could be explained by **Ghassemi *et al.*, (2019)** on *brassica napus* L. plants indicated that foliar application with putrescine further boosted the oil percentage and oil yields under various watering intervals, this resulted indicate a decrease in oil percentage and oil yields under stressful conditions. Also, **Gholami *et al.*, (2013)** showed that drought stress on basil had negative significant effects on yield of essential oil, meanwhile, cytokinins reduced these negative effects.

5. Fatty acids composition:

Date in **Table (4)** show that the major unsaturated fatty acid of chia seeds oil was linolenic (C18:3) followed by linoleic (C18:2) and oleic (C18:1), while the major saturated fatty acids was palmetic (C16:0) followed by stearic (C18:0). It is to be noted that the main component was linolenic acid (50.21 to 53.01) of chia oil.

Concerning the effect of water stress treatments, in general, two water levels 70 and 40 % ETo decreased the unsaturated fatty acids, linolenic (by 52.26, 51.31) followed by linoleic acid (by 21.72, 21.22) compared with control gave (53.01, 22.37) except that oleic acid increased (by 8.68, 8.85) compared with control (8.01). Also it induced a marked decrease in the percentage of total unsaturated fatty acids (by 82.66, 81.40) but increased the total saturated fatty acids (by13.93, 14.49) over the control (by 83.39, 13.09) respectively, in the second growing season.

These results are in agreement with the data obtained by **De Falco *et al.*, (2018)** who showed that deficit irrigation reduced linolenic acid content in response to in chia. Also, **Mahdavi Khorami *et al.*, (2020)** on sesame plants indicated that severe water stress caused decreasing seed oil content and unsaturated fatty acid content, while producing more saturated fatty acids when compared to the control. Furthermore, **Mabudi Bilasvar *et al.*, (2022)** discovered that the unsaturated fatty acids of linoleic and linolenic acids were reduced, and oleic acid was enhanced due to water shortage in rapeseed plants.

As for foliar application treatments, the results in **Table (4)** show that all different concentrations of putrescine and benzyl adenine increased the percentage of the unsaturated fatty acid (i.e. linolenic, linoleic and oleic) and the saturated fatty acids (i.e. palmetic and stearic) as well as the total unsaturated fatty acid and saturated fatty acid in seed oil of chia compared with control. Also, putrescine at 25 ppm gave the maximum values of the percentage of linolenic acid (52.71) and linoleic acid (22.20) followed by benzyladenine at 50 ppm when compared with the untreated plants (51.47 and 21.17).

These results are similar with those obtained by **Abd El-Dayem *et al.*, (2005)** on soybean, **Talaat and Gamal el-ELDin (2007)** on *Nigella sativa* L. and **Mostafa *et al.*, (2005)** on roselle seeds.

Regarding, the interaction effect between applied treatments of putrescine and benzyladenine and water stress levels (70 and 40 % ETo) increased percentage of unsaturated and saturated fatty acids compared with control. Since, it could be noticed that the foliar application with either put at 25 ppm or BA at 50 ppm gave the highest values of the unsaturated and saturated fatty acids under two water stress levels at 70 % and 40 % ETo when compared with the untreated plants and other treatments application. The low concentrations were better than the high concentrations used of both put and BA treatments alone or in combination with water irrigation levels.

In this regard, the present results are in agreement with those of **Mabudi Bilasvar *et al.*, (2022)** on rapeseed plants and **Amirkhiz *et al.*, (2021)** on safflower plants indicated that foliar application of putrescine increased omega 6, polyunsaturated and saturated fatty acids under water stress conditions. The results of this experiment indicate that foliar application of polyamines can increase safflower's grain and oil yield as well as the quality of its fatty acids under irrigation regimes.

Table 2. Effect of water stress levels and applied putrescine and benzyladenine on growth parameters (plant height, number of branches, number of leaves, leaf area, dry weight of stem and dry weight of leaves of chia plant at 80 days after sowing during (2020-2021) and (2022-2023) seasons**.**

Characteristics Water levels (ppm)			Plant height (cm)		Number of branches/plant		Number of leaves/plant		Leaf area (cm^2)/plant		Dry weight of stem (g) /plant		Dry weight of leaves (g) /plant	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
100%	Control	0.0	77.66	81.66	28.00	31.66	65.00	75.66	800.03	1001.96	12.73	20.49	4.03	6.32
	Putresine	25	95.33	97.66	45.00	48.33	93.66	99.33	1106.36	1180.65	25.20	25.72	7.86	11.84
	Putresine	50	86.00	89.11	36.00	40.33	84.66	89.00	1010.23	1026.95	21.00	22.13	5.60	8.96
	Benzyladenine	50	91.00	93.33	40.00	44.33	88.66	95.00	1052.16	1115.82	23.00	23.29	6.80	9.69
	Benzyladenine	100	82.00	85.00	32.33	36.66	75.33	80.33	918.83	1006.65	17.46	21.86	4.66	7.21
70%	Control	0.0	71.66	77.00	22.00	27.00	56.33	71.66	610.36	845.91	11.60	14.04	3.08	5.71
	Putresine	25	90.33	94.55	39.33	44.66	81.33	94.33	1048.90	1090.49	19.36	22.62	6.66	10.92
	Putresine	50	81.00	85.00	30.67	36.66	67.66	84.00	857.20	1003.45	16.33	18.20	4.96	6.99
	Benzyladenine	50	85.66	89.55	34.00	40.33	76.00	90.00	918.60	1051.99	18.40	20.28	5.26	8.92
	Benzyladenine	100	76.33	81.44	26.00	32.66	62.00	78.66	844.10	954.20	14.33	16.48	3.98	5.93
40%	Control	0.0	65.33	71.88	15.00	20.00	47.00	66.33	513.10	745.55	8.20	11.52	2.00	3.92
	Putresine	25	84.66	90.22	33.66	39.66	72.66	88.00	961.33	1016.38	14.70	17.57	5.86	7.92
	Putresine	50	75.33	80.33	24.33	30.00	59.66	77.33	644.10	938.12	10.46	13.56	3.93	5.99
	Benzyladenine	50	80.66	85.33	28.33	34.66	66.00	83.00	893.17	1004.81	12.76	15.94	4.20	6.11
	Benzyladenine	100	71.00	75.88	20.33	25.33	53.66	72.00	606.96	805.03	9.53	12.34	2.38	4.21
L.S.D at 0.05			4.40	3.95	4.15	3.65	5.98	4.47	44.22	50.14	0.997	1.01	1.05	0.62
Water level		100%	74.99	89.35	36.26	40.26	77.46	87.86	977.52	1066.40	19.87	22.69	5.79	8.80
Water level		70%	70.79	85.50	30.40	36.26	68.66	83.73	855.83	989.20	16.00	18.32	4.78	7.69
Water level		40%	65.19	80.72	24.33	29.93	59.79	77.33	723.73	901.97	11.13	14.18	3.67	5.63
L.S.D at 0.05			2.11	2.32	2.25	1.71	3.61	2.00	33.71	37.11	0.79	0.89	0.71	0.40
	Control	0.0	65.88	76.84	21.66	26.22	56.11	71.21	641.16	864.47	10.84	15.35	3.03	5.31
	Putresine	25	75.10	94.14	39.33	44.21	82.55	93.88	1038.86	1095.84	19.75	21.97	5.60	10.22
	Putresine	50	69.77	84.81	21.33	35.66	70.66	83.44	837.17	989.50	15.93	17.96	4.83	7.31
	Benzyladenine	50	72.77	89.40	34.11	39.77	76.88	89.33	954.64	1057.54	18.05	19.83	5.42	8.24
	Benzyladenine	100	68.11	80.77	26.22	31.55	63.66	76.99	789.96	921.96	13.77	16.89	3.67	5.78
L.S.D at 0.05			3.34	3.00	3.32	2.23	4.06	3.18	38.13	41.06	0.88	0.92	0.92	0.51

Table 3. Effect of water stress levels and applied putrescine and benzyladenine on yield and its components (main inflorescences length, number of inflorescences, seed yield, weight of 1000 seed and WUE during (2020-2021) and (2022-2023) seasons and oil percentage during second season (2022-2023) of chia plant at harvest time (150 days after sowing).

Water levels	Characteristics	(ppm)	Main inflorescences length (cm) /plant		Number of inflorescences/plant		Seed yield(g) /plant		Weight of 1000 seed(g)		Oil percentage	WUE (g) /plant	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	2nd season	1st season	2nd season
100%	Control	0.0	20.00	22.66	29.33	36.00	14.14	13.50	1.20	1.20	29.09	0.69	0.67
	Putresine	25	30.66	33.00	41.33	49.66	19.78	20.05	1.40	1.43	33.24	1.06	1.07
	Putresine	50	24.33	27.33	35.33	43.00	17.26	16.79	1.30	1.32	30.99	0.86	0.88
	Benzyladenine	50	27.66	30.00	38.66	46.00	18.02	18.11	1.33	1.36	32.18	0.97	0.97
	Benzyladenine	100	21.00	24.00	32.33	39.33	16.04	15.01	1.26	1.26	30.76	0.70	0.69
70%	Control	0.0	14.66	17.33	25.33	30.33	13.24	12.75	1.15	1.13	28.91	0.83	0.81
	Putresine	25	27.00	29.66	38.66	45.66	17.70	18.39	1.36	1.38	33.08	1.11	1.12
	Putresine	50	21.33	23.00	32.66	39.00	15.90	15.85	1.29	1.30	30.64	1.04	1.06
	Benzyladenine	50	24.00	26.00	35.33	42.00	16.50	16.39	1.32	1.34	31.47	1.09	1.11
	Benzyladenine	100	17.00	20.66	29.00	34.33	14.74	14.32	1.27	1.24	30.46	0.97	0.96
40%	Control	0.0	11.33	14.66	21.66	25.33	11.83	11.76	1.10	1.10	27.60	0.99	0.96
	Putresine	25	24.66	26.66	34.66	40.66	15.23	15.87	1.33	1.33	32.29	1.57	1.58
	Putresine	50	17.66	20.66	28.66	34.66	13.29	13.84	1.25	1.26	30.43	1.31	1.34
	Benzyladenine	50	21.00	23.33	31.33	37.33	14.10	14.29	1.30	1.30	31.28	1.41	1.43
	Benzyladenine	100	14.66	17.33	25.66	31.33	12.49	12.07	1.20	1.20	30.21	1.12	1.10
	L.S.D at 0.05		3.09	3.03	2.00	2.15	0.814	0.787	0.051	0.060	——	0.23	0.25
Water level		100%	24.73	27.39	36.79	42.79	17.04	16.69	1.29	1.31	31.25	0.85	0.85
Water level		70%	20.79	23.33	32.99	38.24	15.61	15.54	1.27	1.27	30.91	1.00	1.01
Water level		40%	17.86	20.52	29.99	33.86	13.38	13.56	1.23	1.23	30.36	1.28	1,28
	L.S.D at 0.05		1.08	1.02	1.03	1.19	0.513	0.506	0.025	0.030	——	0.10	0.12
	Control	0.0	15.33	18.21	25.77	30.55	13.07	12.67	1.15	1.14	28.53	0.83	0.81
	Putresine	25	27.44	29.77	38.21	45.32	17.57	18.10	1.36	1.38	32.87	1.24	1.25
	Putresine	50	21.10	23.66	32.21	38.88	15.48	15.49	1.28	1.29	30.68	1.07	1.09
	Benzyladenine	50	24.22	26.44	35.10	41.77	16.20	16.26	1.31	1.33	31.64	1.15	1.17
	Benzyladenine	100	17.55	20.66	28.99	34.99	14.42	13.80	1.24	1.23	30.47	0.93	0.91
	L.S.D at 0.05		2.18	2.09	1.37	1.82	0.639	0.592	0.031	0.048	——	0.12	0.14

Table 4. Effect of water stress levels and applied putrescine and benzyladenine on percentage of fatty acids composition of chia seed oil in (2022-2023) season.

Water levels	Fatty acids (%) (ppm)	Myristic acid	Palmetic acid	Stearic acid	Arachidic acid	Oleic acid	Linoleic acid	Linolenic acid	Total Saturated Fatty acids	Total Unsaturated Fatty acids	TS:US
		C14:0	C16:0	C18:0	C20:0	C 18:1	C18:2	C18:3			
100%	Control 0.0	0.69	9.00	3.00	0.40	8.01	22.37	53.01	13.09	83.39	1:6.37
70%	Control 0.0	0.70	9.01	3.03	0.41	8.10	21.03	51.20	13.15	80.33	1:6.10
	Putrescine 25	0.83	9.83	3.73	0.54	9.12	22.30	52.99	14.57	84.41	1:5.79
	Putrescine 50	0.79	9.20	3.25	0.50	8.66	21.64	52.31	13.74	82.61	1:6.01
	Benzyladenine 50	0.80	9.49	3.48	0.52	9.09	22.09	52.85	14.29	84.03	1:5.88
	Benzyladenine 100	0.76	9.18	3.19	0.49	8.45	21.57	51.97	13.62	81.99	1:6.01
40%	Control 0.0	0.72	9.12	3.16	0.45	8.15	20.12	50.21	13.45	78.48	1:5.83
	Putrescine 25	0.89	9.90	3.80	0.56	9.14	22.10	52.44	15.15	83.68	1:5.52
	Putrescine 50	0.82	9.62	3.60	0.51	9.00	21.19	51.13	14.55	81.32	1:5.58
	Benzyladenine 50	0.85	9.79	3.76	0.54	9.11	21.90	51.79	14.67	82.80	1:5.64
	Benzyladenine 100	0.80	9.54	3.58	0.50	8.85	20.80	51.00	14.42	80.65	1:5.59
Water levels											
100%		0.69	9.00	3.00	0.40	8.01	22.37	53.01	13.09	83.39	1:6.37
70%		0.77	9.34	3.33	0.49	8.68	21.72	52.26	13.93	82.66	1:5.93
40%		0.81	9.59	3.58	0.51	8.85	21.22	51.31	14.49	81.40	1:5.61
Treatments											
Control 0.0		0.70	9.04	3.06	0.42	8.08	21.17	51.47	13.22	81.72	1:6.10
Putrescine 25		0.86	9.86	3.76	0.55	9.13	22.20	52.71	15.03	84.04	1:5.59
Putrescine 50		0.80	9.41	3.42	0.50	8.83	21.41	51.72	14.13	81.96	1:5.80
Benzyladenine 50		0.82	9.64	3.62	0.53	9.10	21.99	52.32	14.61	83.41	1:5.70
Benzyladenine 100		0.78	9.36	3.38	0.49	8.65	21.18	51.48	14.01	81.31	1:5.80

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تأثير الرش الورقي بالبترسين والبنزيل أدنين علي النمو الخضري والمحصول ومكونات الزيت في بذور نبات الشيا النامي تحت ظروف الإجهاد المائي

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أجريت تجربتان في موسمي (2020 – 2021، 2022 – 2023) علي نبات الشيا لدراسة تأثير الرش الورقي بكل من البترسين (0 ، 25 ، 50 جزء في المليون) والبنزيل أدنين (0 ، 50 ، 100 جزء في المليون) علي صفات النمو والمحصول ومحتوي الزيت ومكونات الأحماض الدهنيه في بذرة نبات الشيا (*Salvia hispanica* L.) تحت ظروف الإجهاد المائي (40 ، 70 % بخر نتح بالإضافة إلي 100% بخر نتح ككنترول) ومن النتائج المتحصل عليها:

1- أدت مستويات الإجهاد المائي 40 ، 70% بخر نتح إلي نقص معنوي في كلاً من صفات النمو الخضري (ارتفاع النبات، عدد الأفرع، عدد الأوراق، مساحة الورقة، الوزن الجاف للسيقان، الوزن الجاف للأوراق) وأيضاً محصول البذور ومكوناته (طول النوره الرئيسية وعدد النورات ومحصول البذور(جرام)/ نبات و وزن 1000 بذرة) في الموسمين وأيضاً نقص النسبه المئوية للزيت والأحماض الدهنيه غير المشبعه (اللينولينك واللينوليك) بالمقارنه بالنباتات الغير معرضه للإجهاد بينما أدت معاملتي الإجهاد المائي إلي زيادة كفاءة استخدام المياه والأحماض الدهنيه المشبعه.

2- أدي الرش الورقي بكل من البترسين (25 جزء في المليون) والبنزيل أدنين (50 جزء في المليون) منفرده أو تحت ظروف مستويات الإجهاد 40 ، 70% بخر نتح إلي زياده معنويه في صفات النمو الخضري والمحصول وكفاءة استخدام المياه في الموسمين وأيضاً زيادة النسبه المئويه للزيت والأحماض الدهنيه الغير مشبعه في الموسم الثاني.

عموماً أظهرت النتائج أن معاملات الرش الورقي بالتركيز المنخفض من البترسين والبنزيل أدنين أفضل المعاملات لتحسين النمو والمحصول ومحتوي الزيت والأحماض الدهنيه في زيت بذرة نبات الشيا تحت الظروف الطبيعيه وظروف الإجهاد المائي.