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Potential Effect of Irrigation Intervals and Potassium Phthalate on Fennel Plants Grown in Semi-Arid Regions

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INCREASING competition on water resources between the agriculture sector and other sectors requires new irrigation regimes to perform relevant levels of production in semi-arid regions. Field experiment was conducted during two successive seasons at the Experimental Farm of EL-Quassassin, Ismailia Governorate, Egypt. This experiment was prepared to assess the effects of different irrigation intervals, potassium phthalate and their combinations on the growth, number of umbels, fruit yield,water use efficiency, and volatile oil production of fennel plant during two successive seasons 2016/2017 and 2017/2018, respectively. Three irrigation treatments, main factor, as follow: I_1 (every three days, which is the common in this region with 1150 m^3/ha), I_2 (every five days with 766 m^3/ha), and I_3 (every seven days with 383 m^3/ha), and the potassium phthalate as subsidiary factor (0, 400,500, and 600 ppm) were applied. The results showed that, the highest vegetative growth parameters were related to the potassium phthalate at the rate of 600 ppm and irrigation interval 3 days.The highest values of fruit yield, as well as the volatile oil production were significantly affected by the potassium phthalate and irrigation frequency in both seasons. Nevertheless, the concentrations of the macro and micro-nutrients in fruits revealed an increasing trend with increasing the irrigation intervals.In addition, the lower the amount of water use, the higher the water use efficiency.The results of GLC analysis of fennel volatile oil indicated that methyl chavicol as the main component varied between (63.02 and 80.82%). The treatment of potassium phthalate at 600 ppm with irrigation every 3 days resulted in the lowest methyl chavicol percentage.Thus, the proper irrigation interval increases the plant water stress tolerance by increasing the water use efficiency and the nutrient concentrations of fruits.

Keywords: Irrigation intervals, Potassium phthalate, Water use efficiency, Fruit yield, Volatile oil.

Introduction

Water resources are a scarce and/or limiting factor for plant production and expanding cultivation areas in arid and semi-arid regions. Climate changes and environmental stresses affect agricultural production and the food supply through their impacts on crop losses and reducing 50% yields for most major crops (Bray et al., 2000 and Bisbis et al., 2018). Egypt is seeking to enhance and increase the cultivated area. However, limited relevant agricultural lands and water resources constrain the Egyptian ambitious expansion plans (Abdel-Mawgowd et al., 2010 and Darwish et al., 2013). Thus Egypt initiated its strategic program that aiming to reclaim more than 600 thousands hectares till 2020. Nevertheless, climate change has compelled scientists, stakeholders, and decision makers to think about the sustainability of water resources future (Bisbiset al., 2018) under the water scarcity situation considering the high rate of population growth and the less water coming from Ethiopia to Egypt (Quda, 2016). Therefore, several scientists (Badr et al., 2010 and Saleh et al., 2012) recommended using of modern irrigation techniques instead of traditional surface irrigation

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such as drip or subsurface drip irrigation.That the efficient water delivery design can contribute to increase crop yield and improving crop water efficiency (Badr et al., 2010). In addition, identify the relevant regimes of the irrigation scenarios are considered a vital strategy to enhance the water use efficiency in arid regions for the irrigation purpose. Therefore, maintaining a sustainable agriculture would require studying the plant response to water shortage and rationing the water for irrigation, especially under the water scarcity in arid regions of the world (Sallam et al., 2014 and Sadik et al., 2018). That is associated with the fact of the steadily growing in population that required increasing in crop yield production to face the food shortage (Howell, 2001). Recently, sustainable farming systems introduce important practices in developing strategies to initiate effective water management regimes and to enhance the water-use for crop production (Howell, 2001 & Abu-hashim and Shaban, 2017). Thus, the approach of deficit irrigation was introduced during the previous era to resolve the problem of food security by using the least amount of water for irrigation (Sallam et al., 2014). Moreover, drought stress has been usually introduced with the cell osmotic adjustment that resulted from accumulation of several compounds such as polyols, soluble sugars, proline, and other organic compounds (Chai et al., 2001 and Sallam et al., 2014). As a result of the water scarcity in arid regions, the full irrigation did not consider a strategic option. In arid areas where water availability is the most limiting factor, increasing water productivity could be economically more profitable than maximizing yields and their stabilization for the farmer. In other words, deficit irrigation aims at stabilizing yields and obtaining maximum water productivity rather than maximum yields (Zhang and Oweis, 1999).

For the arid region areas of water scarcity phenomena and long summer drought, such El-Quassassin, Ismailia (Suez Canal, Egypt), deficit irrigation strategies is extremely recommended to mitigate the yield reductions (Kirda et al., 2004). The awareness of the water supply concept and the relationships between water intervals and crop yield could help the policy makers and the farmers to optimize water management. Using half of the required water supply during vegetative growth showed higher yield than applying the full irrigation. Moreover, the decrease in the soil water availability restrict the diffusion rate of soil nutrients, a decrease of the plant nutrient uptake, and/or the composition of soil solution (Marschner, 1986).

Foeniculum vulgare Mill (fennel) belongs to familyApiaceae (Umbelliferae),is one of the economic crops in arid regions. Its fruits and volatile oil are used in food industry, cosmetics and medicine (Stary and Jirasek, 1975). Ruberto et al. (2000) reported that fennel plant possess several medicinal properties as carminative, antispasmodic antioxidant and anti-microbial. Drought stress is one of the main abiotic stress factors limiting growth and productivity of fennel crop more than any other stress (Ghannoum, 2009) and these effects irreversibility depends on the genotype, duration, intensity and plant development stage. That the drought affects the water status growth, development, yield, membrane integrity and osmotic adjustment (Praba et al., 2009). The plant`s ability to sustain integral physiological processes such as photosynthesis and gas exchange during drought stress, especially in the phases regarded sensitive to the crop,reflects the potential indicators for maintaining productivity under water limiting conditions (Silva et al., 2007). As the key process of primary metabolism, photosynthesis plays a key role in fennel performance under drought stress(Pinheiro and Chaves, 2011). The balance between light capture and energy use are of great relevance to studies concerning the responsiveness of the photosynthetic apparatus to drought stress (Chaves et al., 2009). Photosynthesis is directly affected by drought and stomatal closure allows the plants to limit transpiration, but it also reduceCO_2 absorption, which ultimately results in limited photosynthesis activity (Nayyar and Gupta,2006). Other variables related to gas exchange such as stomatal conductance and transpiration being very sensitive to drought stress and having a good correlation to photosynthesis, have also been identified aspromising attributes for induction of drought tolerance in plants (Endres et al., 2010).

Phthalic acid (1,2 benzenedicarboxylic acid)is phenolic compound of hormonal type that naturally produced by plant.Phthalic acid consists of two carboxylic groups attached or linked to benzene ring (Lafayand Gil-Izquierdo, 2008). It is a plasticizer compound possessing antimicrobial properties.Phthalic acid also used in neurodegenerative diseases. Organic compounds are exudated toward the rizosphereto facilitate the assimilation of mineral nutrients (Van Hees et al., 2000). Phthalic acid is one of benzoic acid derivatives. Benzoic acid considered as a biosynthetic precursor of salicylic acid. Benzoic acid is potentially known to provide abiotic stress tolerance (Senaratna et al., 2003).

Potassium (K) plays essential roles in enzyme activation, protein synthesis photosynthesis, osmoregulation stomatal movement, energy transfer, phloem transport, cation-anion balance and stress resistance (Marschner, 2012). K nutrition not only increased plant total dry mass and leaf area, but also improved the water retention in plant tissues under drought stress (Lindhauer,1985). On maize plants,(Premachandra et al.,1991) reported that higher application of K showed greater adaptation to water stress. So occurrence of water stress in arid regions with the plant developmental stages would decreases seed yield through reducing the duration of photosynthesis period. In addition, water limitation influences seed yield by reducing cell division and elongation. Therefore, to meet the plant water demand during the short period of pollination until seed filling stage to obtain optimum seed yield.Thus the effect of the irrigation intervals associated with potassium phthalate on fruit yield of fennel plants should be investigated. The aim of this experiment was to investigate the effect of different irrigation intervals, potassium phthalate and their combinations on improvement of drought tolerance, based upon modulation in growth, fruit yield, water use efficiencyand volatile oil production under drought stress periods.

Materials and Methods

Field experiment was conducted during two successive seasons of 2016/2017 and 2017/2018 at the Experimental Farm of EL-Quassassin, Horticulture Research Station, Ismailia Governorate, Egypt. The region (Fig. 1) characterized with continental climate of hot dry summers and rather wet winter. The lowest temperature is January and February (21 C^{o} and 20 C^{o}), and the maximum amount of rainfall is 15.7 mm/month in February. The highest humidity percent is 75 % in January (Meteorological Station of Port Said/El Gamil, 2017-2018 (3128 N and 3223 E).

The soil texture was sandy and had pH 7.60, EC 0.75 dSm^{-1}, organic matter 3.50 g kg^{-1} and $CaCO_3$4.00 g kg^{-1} (Table 1), and the physico-chemical properties of the investigated soil are characterized according to Page et al. (1982).

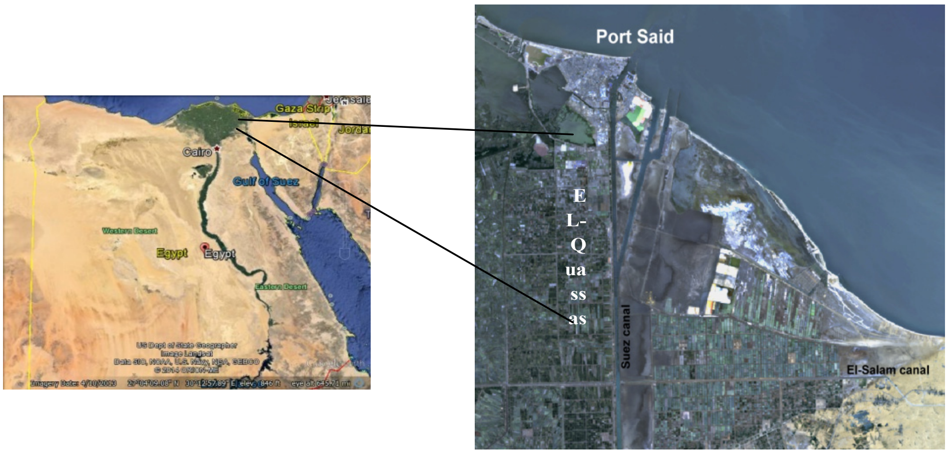

Fig.1. Experimental location of EL-Quassassin, Horticulture Research Station, Ismailia Governorate, Egypt

TABLE 1. Physical and chemical properties of the investigated soils

Properties	**Value**	**Properties**	**Value**
Soil particles distribution (%)		Soluble cations and anions (mmolc/L)**	
Sand	90.87	Ca^{++}	2.52
Silt	6.03	Mg^{++}	1.28
Clay	3.10	Na^{+} 2.87	
Textural class	Sandy	K^{+} 0.89	
Field capacity (FC) %	11.50	$CO_3^{=}$ 0.00	
$CaCO_3$, (gkg^{-1})	4.00	HCO_3^{-} 2.52	
Organic matter (gkg^{-1})	3.50	Cl^{-} 3.60	
pH*	7.60	$SO_4^{=}$ 1.46	
EC dSm^{-1}**	0.75	Total P (gkg^{-1})0.14	
		Available P (mg kg^{-1}soil) 17.42	

* Soil suspension (1:2.5)** Paste extract

Layout of the experiment

The fruits of fennel (*Foeniculum vulgare*) were obtained from the Experimental Farm of Medicinal and Aromatic Plants Research Department. The soil was prepared and divided into plots, each of them was 3.6 m^2.The experiment layout was designed in split plot included twelve (12) treatments. Each treatment was replicated three times and every replicate composedof twenty (20) plants. Irrigation intervals occupied the main plots, while potassium phthalate (anti-stress agent) was arranged in sub plots.The analysis of variance (ANOVA) was conducted and the means of the treatments were compared using L.S.D. at 5% according to Snedecor and Cochran (1980).

Chemical fertilization

Chemical fertilizers (NPK) were ammonium sulphate (20.6% N), calcium super phosphate (15.5% P_2O_5), and potassium sulphate (48% K_2O). NPK fertilizers were added at the recommended level in three doses, phosphorous fertilizer was added during the soil preparation, while N and K fertilizers were applied in two equal doses the 1st was applied 45 days after sowing and the second was added 30 days later.

Irrigation scheme and potassium phthalate application

The design of the irrigation regime in this experiment was drip irrigation system (DIS), and has been designed according to the experimental design. The discharge of each emitter was 2L/hr. The fruits were sown on 6thNovember in the two seasons. The irrigation scheme was applied depend on the interval approach. Irrigation intervals throughout the entire growth period of crop were: I_1= irrigation every 3 days (1150 m^3/ha) I_2= irrigation every 5days (766 m^3/ha) and I_3= irrigation every 7 days (383 m^3/ha). These irrigation intervals were applied 30 days after sowing.

Potassium phthalate (PhK) was sprayed at 0,400,500 and 600 ppm.Spraying was started30 days from sowing and repeated at 30 day intervals for the 2nd and 3rd.

Data recorded

- Plant height (cm).
- Number of branches/ plant.
- Number of umbels / plant.
- Fruit yield (g) / plant.
- Seed index as weight of 100 seeds.
- Volatile oil percentage was determined according to British Pharmacopeia (1963).
- Volatile oil yield (ml)/ plant.
- Chemical composition of volatile oil (GLC) analysis as described by (Hoftman, 1967 and Bunzenet al., 1969).
- The macro and micro-nutrients were determined according to the methods of (Page et al., 1982).

Results and Discussion

Vegetative growth parameters

Data presented in Table 2 showed the growth characters (plant height and number of mainbranches/plant) of fennel during the two successive seasons.The results revealed that, the plant height and the number of branches/plant were significantly affected by irrigation intervals and potassium phthalate treatments.

It was observed that, there was considerable reduction in plant height and number of main branches/plant of fennel plants subjected to drought stress as compared to usual water in both seasons. It was clear from data in Table 2 that, increasing irrigation intervals from 3 to 7 days led to a significant decrease in plant height and number of main branches/plant. The maximum values of growth parameters were obtained as a result of I_1 treatment compared with the other water supply treatments. These results agree with those reported by Sabih et al. (1999) on palmrosa, (Misra and Srivastava, 2000) on Japanese mint, (Khalid, 2006) on *Ocimum* sp, (Khalil et al., 2012) on *Jatropha curcas* L. and Bahreininejad et al. (2013) on *Thymus daenensis*.

As for the effect of anti-stress agent on plant height, exogenous treatments with potassium phthalatehad a significant effect on plant height of fennel plants in both season. Tallest plants were those treated with potassium phthalate at 600 ppm giving 177.45 and 184.89 cm in the first and second seasons,respectively. Control plants were the shortest plants giving 168.89 cm for the first season and 175.87 cm for the second one.These results are in accordance with (Shakeel et al., 2013) on soybean.

The interaction between irrigation intervals and potassium phthalate hada significant effect on plant height of fennel. Data in Table 2 showed that,the highest values 180.67 and 190.33 cm in the two seasons, were obtained as result of I_1 treatment combined with foliar application of potassium

TABLE 2. Effect of irrigation intervals and potassium phthalate treatments on plant height (cm) and number of branches/plant of *Foeniculum vulgare* in 2016/ 2017 and 2017/2018

	1st season				2nd season			
	Plant height (cm)							
Irrigation / ANS	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**
Control	178.67	174.67	153.33	168.89	186.33	178.33	163.00	175.87
Phk_1 (400 ppm)	183.33	172.67	157.67	171.22	188.67	180.67	167.00	178.78
Phk_2(500 ppm)	180.65	175.67	166.00	174.11	189.00	183.33	172.00	181.44
Phk_3 (600 ppm)	180.67	177.00	174.67	177.45	190.33	186.00	178.33	184.89
Mean	180.83	175.00	162.92		188.50	182.08	170.08	
LSD at 5% Irrigation	2.13				1.19			
LSD at 5% ANS	2.42				1.29			
LSD at 5% Interaction	3.99				2.13			
	Number of branches/plant							
Control	11.33	8.67	5.00	8.33	12.33	10.33	6.33	9.66
Phk_1 (400 ppm)	12.33	9.33	5.67	9.11	13.33	10.67	7.00	10.33
Phk_2(500 ppm)	13.00	10.00	7.33	10.11	14.67	11.67	8.00	11.45
Phk_3 (600 ppm)	14.33	11.00	8.33	11.22	15.67	12.00	9.00	12.22
Mean	12.75	9.75	6,58		14.00	11.17	7.58	
LSD at 5% Irrigation	0.86				1.11			
LSD at 5% ANS	0.58				0.57			
LSD at 5% Interaction	NS				NS			

I_1 = 3 days ANS = antistress agent= Ph k_1 = potassium phthalate = 400 ppm
I_2 = 5 days ANS = antistress agent= Ph k_2 = potassium phthalate = 500 ppm
I_3 =7 days ANS = antistress agent= Ph k_3 = potassium phthalate = 600 ppm

phthalate at 600 ppm. These results agree with Said & Hussein (2010) and Sary & Elsokkary, (2019) mentioned that the improvement of plant nutrition can contribute to increase resistance and production when the crop issubmitted to water stress. Potassium has an important role in plants survival under environmental conditions.

The same trend was observed in number of branches/plant the highest number of branches was recorded when the plants were irrigated every 3 days (I_1) giving 12.75 and 14.00 branches/plant in the first and second seasons, respectively. Such results might be reasonable, since (Doorenbos and Pruitt, 1979) mentioned that more frequent irrigation periods gave chance for more luxuriant use of soil moisture, which ultimate resulted in greater foliage and increase of transpiration. As a result of vegetative growth promotion, the absorption of nutrient elements could be increased. The metabolic processes can also promoted.

Regarding the effect of potassium phthalate on number of branches data presented in Table 2 showed that, the highest values were obtained when fennel plants treated with potassium phthalate at 600 ppm giving 11.22 and 12.22 branches/plant in the first and second seasons, respectively. Concerning the effect of interaction on number of branches/plant the results showed insignificant differences in both seasons.

Flowering

Data in Table 3 indicated that, number of umbels was positively affected by irrigation frequency. The best results were obtained when fennel plants irrigated every 3 days (I_1). The values were 32.84 and 34.17 umbels /plant in both seasons. Increasing irrigation intervals significantly decreased number of umbels in the two seasons. The lowest number of umbels were obtained when the plants irrigated every 7 days giving 17.83 and 19.08 umbels /plant in the first and second seasons, respectively. These results were fortified by (Anupamaet al., 2005) on chrysanthemum,pointed out that, number of flowers/ plant increased with increasing frequency of irrigation.

TABLE 3. Effect of irrigation intervals and potassium phthalate treatments on number of umbels / plant of *Foeniculum vulgare* in 2016/ 2017 and 2017 / 2018 seasons

Number of umbels/plant								
	1st season				2nd season			
Irrigation \ ANS	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
Control	26.00	19.33	13.67	19.67	27.33	20.00	15.00	20.78
Phk_1 (400 ppm)	29.00	20.33	16.00	21.78	30.33	21.00	16.67	22.67
Phk_2(500 ppm)	33.67	23.67	17.33	24.89	35.33	25.67	19.00	26.67
Phk_3 (600 ppm)	42.67	27.00	24.33	31.22	43.67	29.33	25.67	32.89
Mean	32.84	22.58	17.83		34.17	24.00	19.08	
LSD at 5% Irrigation	1.91				3.29			
LSD at 5% ANS	2.11				2.20			
LSD at 5% Interaction	3.48				NS			

I_1 = 3 days ANS = antistress agent = Ph k_1 = potassium phthalate = 400 ppm
I_2 = 5 days ANS = antistress agent = Ph k_2 = potassium phthalate = 500 ppm
I_3 =7 days ANS = antistress agent = Ph k_3 = potassium phthalate = 600 ppm

As for the effect of anti-stress agent (potassium phthalate) on number of umbels /plant, spraying fennel plants with potassium phthalate had a significant effect on number of umbels/ plant in the two seasons. The highest number of umbels/ plant was recorded when fennel plants treated with potassium phthalate at 600 ppm in both seasons. The values were 31.22 and 32.89 umbels /plant in the first and second seasons, respectively. Control plants gave the lowest number of umbels in the two seasons. Such effect duetothe protective role of potassium in stress by maintain high pH in the stomata and the oxidative damage to chloroplast (Romheld and Kirby, 2001).

Interaction between irrigation intervals and potassium phthalate treatments had a significant effect on number of umbels /plant in the first season. The most efficient treatment was potassium phthalate at 600 ppm with 3 days (I_1) irrigation intervals which gave the highest number of umbels /plant in the first season. While in the second season, there were no significant differences between treatments. These results agree with those reported by Valadabadi and Farahani (2010) on corn.

Fruit yield characteristics

Fruit yield

Effect of irrigation intervals and potassium phthalate and their combinations on fruit yield was tabulated in Table 4. It could be noticed that, irrigating frequency had a significant effect on fruit yield in both seasons. The most efficient results were obtained when fennel plants irrigated every 3 days (I_1). The values were (48.37 and 48.89g/plant) in the first and second seasons, respectively. The results are associated with (Hassan et al., 2012) on coriander and (Mohammad javad et al., 2013) on fenugreek. Increasing irrigation intervals from I_1 to I_3 led to a decrease in fruit yield in the two seasons. These results may be explained through the findings of kang et al. (2002) on wheat and Goksoy et al. (2004) on safflower, that the occurrence of water deficit stress at different developmental stages, particularly during reproductive stage, decreases seed yield through reducing the duration of photosynthesis period, the mobilization of assimilates to seeds and the contribution of retrains location of stem reserves to seeds.

Water limitation influencesseed yield by reducing cell division and elongation as well as bydecreasing mobilization of current assimilates and the retrains location of produced materials to seeds. Therefore, it is necessary to meet plant water demand during the short period of pollination until seed filling stage in order to obtain optimum seed yield (Gijón et al., 2009 and Galindo et al., 2016).

Regarding the effect of potassium phthalate on fruit yield of fennel plants, the obtained results in Table 4 showed that, increasing the concentration of potassium phthalate from 0 to 600 ppm significantly increased fruit yield in both seasons. The highest fruit yield was obtained by spraying potassium phthalate at 600 ppm. The values were (45.28 and 45.55 g/plant) in the first and second seasons, respectively. Such effect may be attributed to potassium essential roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomata movement, energy transfer, cation-anion balance and stress resistance. Moreover, the presence of one carboxylic group or more is necessary for growth activity (Marschner, 2012). Benzene carboxylic acids include monocarboxylic acid such as benzoic acid as well as polycarboxylic acids like phthalic acid. These acids have been employed as building block synthons for the systhesis of metal carboxylate compounds with novel structural features. Metal carboxylates are consist of metal sources (metals/metal salt as base) and organic acids. Metal carboxylates derived from benzene di (phthalic acid) and tricarboxylic acids, these compounds exhibit porosity as well as sorption properties. Alsometal carboxylates can serve as models of active sites of some enzymes.

The positive effect of carboxylic acid on yield may be due to the vital effect of this carboxylic acid for stimulating the growth and increasing yield (Abdallah et al., 2015). These results are in good agreement with those obtained by Tuna et al. (2007) on maize, Bukhsh et al. (2009) on sunflower, and Abdel-Hakim et al. (2012) on snap bean. The increase in seed yield could be a reflection of the positive effect of potassium phthalate on growth and development, which induced an increment of growth characters in the term of (plant height and number of branches)consequently enhance the plant potentiality to carry more umbels and hence more fruits. Moreover, the results of Table 4 revealed a significant effect of the interaction between irrigation intervals and potassium phthalate on fruit yield of fennel plants. The application of irrigation interval every 3 days (I_1) combined with potassium phthalate at 600 ppm gave the highest values (53.00 and 53.20 g / plant) in the first and second season, respectively. These results are associated with the results obtained by Valadabadi and Farahani (2010).

TABLE 4. Effect of irrigation intervals and potassium phthalate treatments on fruit yield and seed index as weight of 100 seeds(g) of *Foeniculum vulgare* in 2016/ 2017 and 2017/2018 seasons

	1st season				2nd season			
	Fruit yield/ plant (g)							
Irrigation / ANS	I_1	I_2	I_3	**Mean**	I_1	I_2	I_3	**Mean**
Control	45.20	39.20	27.58	37.33	45.78	40.06	28.75	38.20
Phk_1 (400 ppm)	46.59	40.08	30.27	38.98	47.27	40.70	36.19	41.39
Phk_2(500 ppm)	48.67	41.30	37.90	42.62	49.30	43.67	38.20	43.72
Phk_3 (600 ppm)	53.00	44.13	38.70	45.28	53.20	44.61	38.83	45.55
Mean	48.37	41.18	33.61		48.89	42.26	35.49	
LSD at 5% Irrigation	0.84				0.58			
LSD at 5% ANS	1.80				1.28			
LSD at 5% Interaction	2.83				2.01			
	Seed index as weight of 100 seeds (g)							
Control	1.25	1.08	0.82	1.05	1.27	1.13	0.86	1.09
Phk_1 (400 ppm)	1.30	1.12	0.83	1.08	1.32	1.14	0.87	1.11
Phk_2(500 ppm)	1.31	1.15	0.95	1.14	1.33	1.20	1.01	1.18
Phk_3 (600 ppm)	1.33	1.23	0.98	1.18	1.36	1.25	1.10	1.24
Mean	1.30	1.15	0.90		1.32	1.18	0.96	
LSD at 5% Irrigation	0.07				0.09			
LSD at 5% ANS	0.04				0.04			
LSD at 5% Interaction	NS				0.08			

I_1 = 3 days ANS = antistress agent= Ph k_1 = potassium phthalate = 400 ppm
I_2 = 5 days ANS = antistress agent= Ph k_2 = potassium phthalate = 500 ppm
I_3 =7 days ANS = antistress agent = Ph k_3 = potassium phthalate = 600 ppm

Seed index as weight of 100 seeds

The results of Table 4 showed that, irrigation intervals had a significant effect on the weight of 100 seeds in the two seasons. Irrigation every 3 days (I_1) was the most efficient treatment that gave (1.30 and 1.32 g/100 seeds) in both seasons. These results are consistent with Koocheki et al. (2006) on fennel.

Furthermore, the results revealed that, the weight of 100 seeds significantly increased with increasing the concentration of potassium phthalate compared to the control in the two seasons. As for the interaction effects between irrigation intervals and potassium phthalate treatments, although the plants treated with potassium phthalate at 600 ppm and irrigated every 3 days (I_1) resulted in the heaviest weight of 100 seeds in both seasons, there were no significant differences between these treatments in the first season. These results are associated with those obtained by (Seghatoleslami et al., 2013) on fenugreek.

Nutrients concentration in fruit yield

Table 5 showed the results of the impact of irrigation intervals and the potassium phthalate treatments and their combinations on the macro and micro-nutrientsconcentrations in the fruit yield. For the macro-nutrients, increasing the irrigation intervals under the highest dose of potassium phthalate at 600 ppm from three days and 5 days to seven days revealed an increasing trend of the N, P, and K concentrations (1.06, 1.22, and 1.35%), (0.40, 0.48, and 0.52 %), and (2.16, 2.26, and 2.34 %) respectively. The same results of the micro-nutrients were obtained with increasing thewater stress. Increasing the irrigation intervals under the highest treatment of potassium phthalate at 600 ppm from three days and 5 days to seven days revealed an increasing trend of the Fe, Mn, and Zn concentrations (55.87, 73.02 and 77.12 ppm), (37.64, 40.66 and 48.30 ppm), and (18.75, 26.88 and 30.43 ppm), respectively. Moreover, the impact ofincreasing the potassium phthalate doses under the same irrigation regime showed an increasing trend in the concentration of the macro and micro-nutrients concentrations compared to the control treatment (Table 5). These results are associated with the interpretation of (Marschner, 2012) for the roles of the Potassium (K) in enzyme activation, osmoregulation stomatal movement, energy transfer, phloem transport, and stress resistance. Moreover, (Lindhauer, 1985 and Premachandra et al., 1991) mentioned that K nutrition not only increased plant total dry mass and leaf area, but also improved the water retention in plant tissues under drought stress.That the higher application of K showed greater adaptation to water stress. This improvement was mainly attributed to the role of K in improving cell membrane stability and osmotic adjustment ability. An adequate K supply is essential to enhancing drought resistance by increasing root elongation and maintaining cell membrane stability and increase the ability of the roots to absorb the macro and micro nutrients as displayed in Table 5.

TABLE 5. Effect of irrigation intervals, and potassium phthalate treatments on Macro and Micro nutrients in fruit yield

Treatments	Macronutrients (%)			Micronutrients (mg/kg)		
	N	P	K	Fe	Mn	Zn
I_1_Control	0.89	0.25	1.89	50.34	32.90	16.86
I_1_Phk$_1$(400 ppm)	0.94	0.28	2.04	52.90	30.75	17.45
I_1_Phk$_2$ (500 ppm)	0.92	0.31	2.07	48.23	34.99	14.99
I_1_Phk$_3$ (600 ppm)	1.06	0.40	2.16	55.87	37.64	18.75
I_2_Control	1.12	0.36	2.13	62.40	35.77	20.56
I_2_Phk$_1$(400 ppm)	1.16	0.38	2.18	61.95	38.98	22.85
I_2_Phk$_2$ (500 ppm)	1.14	0.43	2.20	65.88	43.22	24.30
I_2_Phk$_3$ (600 ppm)	1.22	0.48	2.26	73.02	40.66	26.88
I_3_Control	1.28	0.47	2.24	75.26	45.90	28.56
I_3_Phk$_1$(400 ppm)	1.33	0.45	2.23	76.34	47.77	31.00
I_3_Phk$_2$ (500 ppm)	1.32	0.47	2.28	75.86	45.80	32.56
I_3_Phk$_3$ (600 ppm)	1.35	0.52	2.34	77.12	48.30	30.43

I_1 = 3 days ANS = antistress agent= Ph k1 = potassium phthalate = 400 ppm
I_2 = 5 days ANS = antistress agent= Ph k 2 = potassium phthalate = 500 ppm
I_3 = 7 days ANS = antistress agent= Ph k3 = potassium phthalate = 600 ppm

Water use efficiency (WUE)

The amount of water used to produce 1 g of fennel fruit yield dry matter as influenced by the irrigation intervals is illustrated in Fig 2. The results showed that the lower the amount of water use, the higher the water use efficiency. The highest water use efficiency was obtained from the 7-day irrigation intervals while lowest water use efficiency was foundbetween3 and 5 day irrigationinterval even they reveled higheryield. These results were associated with the finding of (Ismail and Kiyoshi, 2009) reported that, increasing the irrigation intervals revealed an increase on the WUE of Chile pepper. Moreover, Kang et al. (2001); Dorji et al. (2005) and Abu-hashim & Shaban (2017) reported that the WUE of the crops under the semi-arid regions enhanced with increasing the irrigation intervals and with using the deficit irrigation management by irrigating the crop with lower amount of water than the amount required for evapo-transpiration.

Volatile oil production

Volatile oil percentage in fennel fruits and volatile oil yield ml/ plant were significantly responded to irrigation intervals, potassium phthalate treatments and their interactions as resulted in Table 6.

Volatile oil percentage and volatile oil yield

Data in Table 6 indicated that,irrigation intervals had a significant effect on fruits volatile oil percentage and yield per plant in the two seasons. Plants irrigated every 3 days (I_1) gave the highest values ofvolatile oil percentage (1.86 and 1.90 %), while in case of volatile oil yield, the same trend of oil percentage was also observed, so the highest values of volatile oil yield were recorded with I_1 (0.91 and 0.93 ml / plant) in the first and second seasons, respectively. The increment in volatile oil yield could be explained through the increment in fruit yield as aresult of using the shortest irrigation intervals. These results agree with those obtained by Osman & El- Fiky (2005) and Hassan et al. (2012) on coriander plants.

Regarding the potential effect of potassium phthalate treatments, the most efficient treatment was potassium phthalate at 600 ppm which gave the highest volatile oil percentage and yield/plant over untreated plants. These values (1.64 and 1.69 %) for volatile oil percentage and (0.76 and 0.78 ml/plant) in the first and second seasons, respectively. These results may be interpreted as the positive effect of potassium phthalate on increasing nutrients uptake and photosynthesis rate.

For the interaction between potassium phthalate doses and irrigation intervals, the treatment of potassium phthalate at 600 ppm with 3 days irrigation intervals (I_1) revealed the highest oil percentage (1.96 and 2.00%), and oil yield/plant (1.04 and1.06 ml/plant) for the first and the second seasons, respectively. These results are in agreement with those obtained by Hassan et al. (2012) on coriander.

Volatile oil constituents

Data in Table 7 and Fig. 3-6 showed the GLC analysis of fennel fruits volatile oil in the second season, for the treatments of I_1 (those plants irrigated every 3 day), I_1+ Phk_3 (potassium phthalate at 600 ppm), I_2 (those plants irrigated every 5 day), and I_2+Phk_3.The obtained results indicated that irrigation intervals, potassium phthalate and their combinations affected the percentage of volatile oil components, methyl chavicol percentage, which the main component varied between 63.02 and 80.82%. The treatment of I_1+Phk_3 resulted in the low estmethyl chavicol percentage (63.02%) while the highest value (80.82%) was obtained by I_2 (those plants irrigated every 5 day). As for anethole, this compound recorded the highest value (1.62%) in volatile oil with the treatment (I_2+Phk_3) followed by the treatment (I_1+Phk_3) which gave (1.00%). It could be concluded that, the interaction between the shortest irrigation intervals and the high dose of potassium phthalate (I_1+Phk_3) had a positive effect on volatile oil quality.

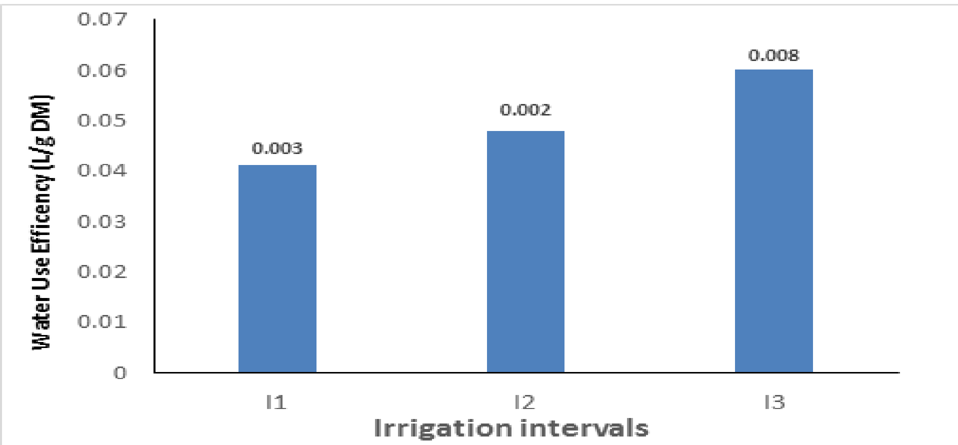

Fig. 2. Effect of irrigation intervals on water use efficiency of fennel fruit yield. Numbers above each column display St. dev. of the different treatments under each irrigation regime

TABLE 6. Effect of irrigation intervals and potassium phthalate treatments on volatile oil production of *Foeniculum vulgare* in 2016/ 2017 and 2017/2018 seasons

	1st season				2nd season			
	Volatile oil percentage (%)							
Irrigation / **ANS**	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**
Control	1.73	1.41	1.01	1.38	1.78	1.45	1.14	1.46
Phk_1 (400 ppm)	1.84	1.44	1.21	1.50	1.87	1.50	1.27	1.55
Phk_2(500 ppm)	1.92	1.53	1.32	1.59	1.95	1.57	1.36	1.63
Phk_3 (600 ppm)	1.96	1.62	1.35	1.64	2.00	1.68	1.38	1.69
Mean	1.86	1.50	1.22		1.90	1.55	1.29	
LSD at 5% Irrigation	0.01				0.01			
LSD at 5% ANS	0.01				0.01			
LSD at 5% Interaction	0.02				0.01			
	Volatile oil yield/ plant (ml)							
Control	0.79	0.55	0.28	0.54	0.82	0.58	0.33	0.58
Phk_1 (400 ppm)	0.86	0.58	0.36	0.60	0.88	0.61	0.46	0.65
Phk_2(500 ppm)	0.93	0.63	0.50	0.69	0.96	0.69	0.52	0.72
Phk_3 (600 ppm)	1.04	0.71	0.52	0.76	1.06	0.75	0.54	0.78
Mean	0.91	0.62	0.42		0.93	0.66	0.46	
LSD at 5% Irrigation	0.03				0.02			
LSD at 5% ANS	0.03				0.02			
LSD at 5% Interaction	0.05				0.03			

I_1= 3 days ANS = anti stress agent = Phk1 = potassium phthalate = 400 ppm
I_2= 5 days ANS = anti stress agent = Phk2 = potassium phthalate = 500 ppm
I_3= 7 days ANS = anti stress agent = Phk3 = potassium phthalate = 600 ppm

TABLE 7. Effect of irrigation intervals and potassium phthalate treatments on GLC analysis volatile oil production of *Foeniculum vulgare*

Treatments	α pinene	Limonene	1,8 cineol	Methyl chavicol	Fenchyl acetate	Anethole
I_1	1.92	13.70	2.88	79.03	0.49	0.76
I_{1+} Phk_3	0.94	11.91	6.21	63.02	12.63	1.00
I_2	1.31	13.40	3.45	80.82	0.57	0.45
I_{2+} Phk_3	1.02	11.89	2.48	80.28	1.74	1.62

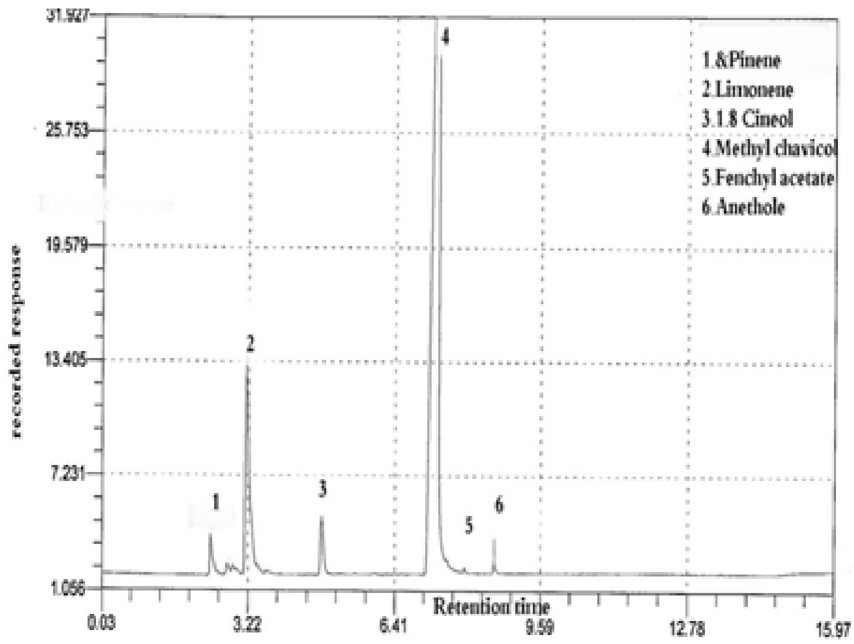

Fig. 3. Chromatograph of fennel volatile oil under I_1

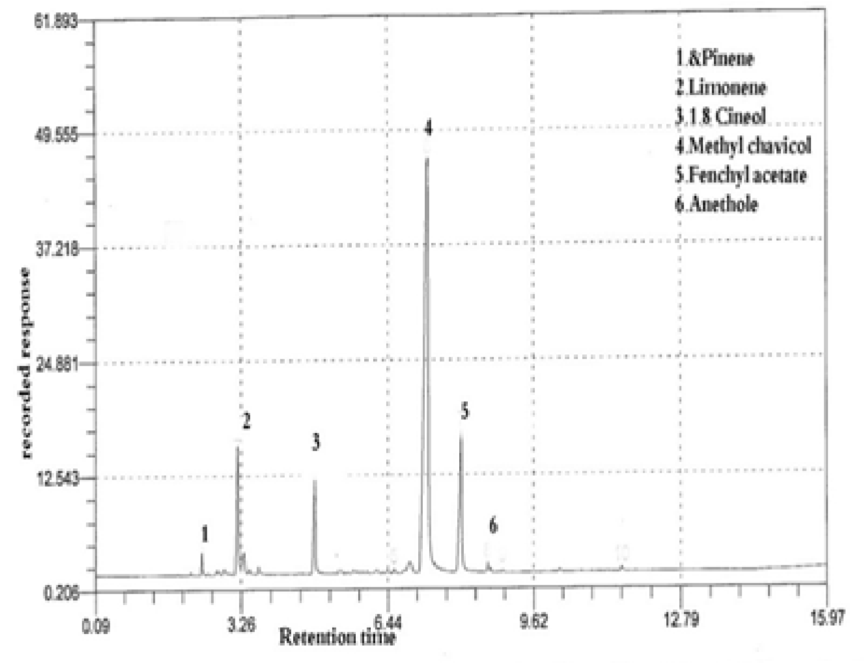

Fig. 4. Chromatograph of fennel volatile oil under I_1+Phk_3

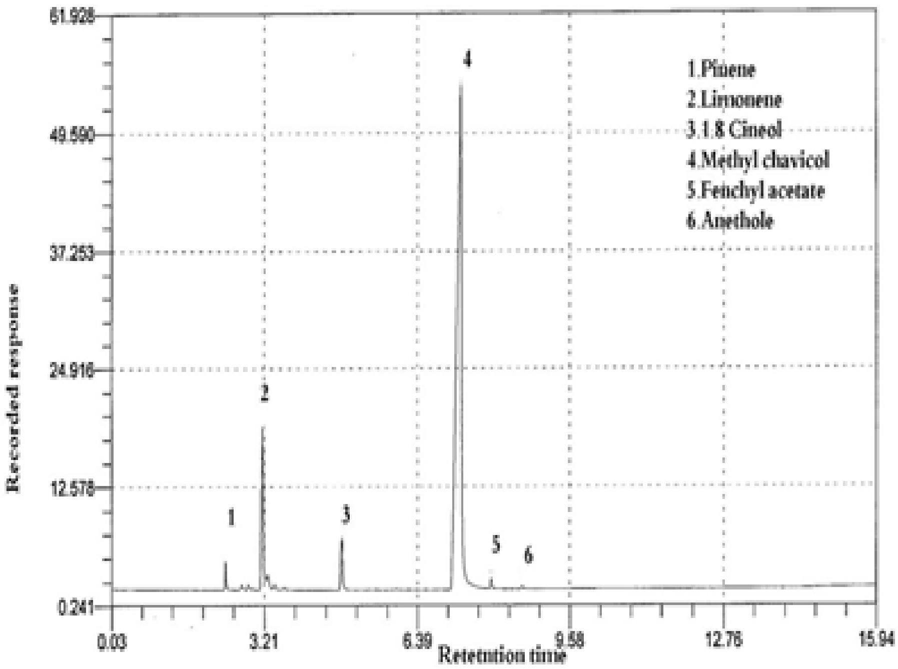

Fig. 5. Chromatograph of fennel volatile oil under I_2

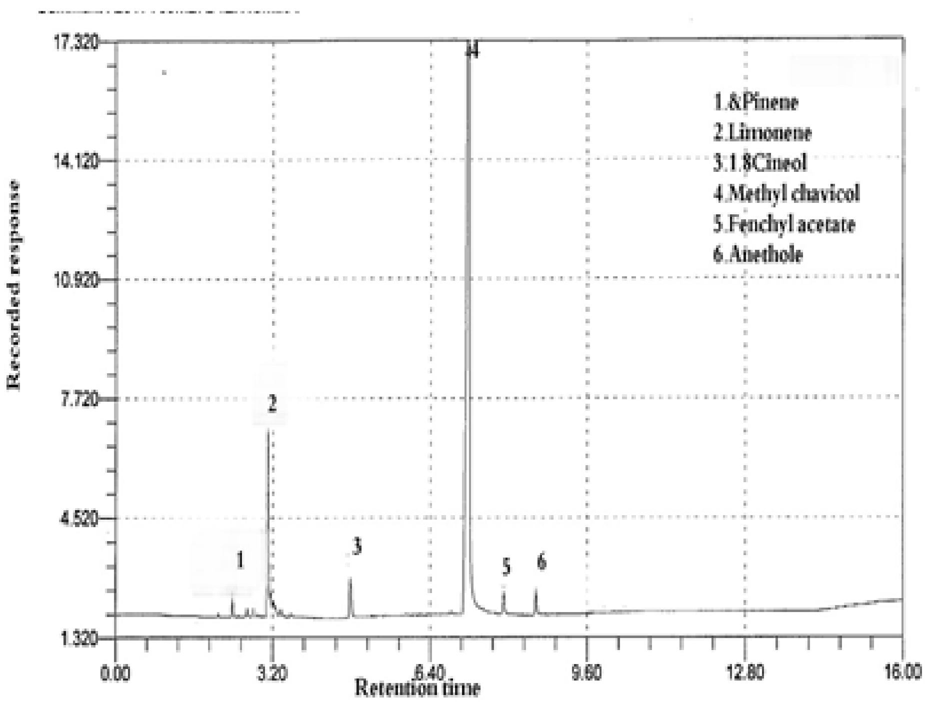

Fig. 6. Chromatograph of fennel volatile oil under I_2+ Phk_3

Conclusion

The occurrence of water deficit stress in semi-arid regions at different plant developmental stages, mainly during the reproductive stage, would decreases seed yield through reducing the duration of photosynthesis period, the mobilization of assimilates to seeds and the contribution of retrains location of stem reserves to seeds. Water limitation influences seed yield by reducing cell division and elongation as well as by decreasing the mobilization of current assimilates and the retrains location of produced materials to seeds. Therefore, it is necessary to meet plant water demand during the short period of pollination until seed filling stage in order to obtain optimum seed yield.The effect of the irrigation intervals associated with potassium phthalate on fruit yield of fennel plants was pronounced. That application of irrigation interval every 3 days (I_1) combined with potassium phthalate at 600 ppm gave the highest values.

Thus we conclude that for the fennel production in semi-arid regions, increasing the irrigation intervals from 3 days to 5 days increase the water use efficiency and save 35 % of the amount of water that could be used for irrigation in these regions.

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التاثير المحتمل لفترات الرى وفاثيلات البوتاسيوم على نباتات الشمر النامية فى المناطق شبه الجافة

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اجريت تجربة حقلية فى مزرعة التجارب فى محطة بحوث البساتين بالقصاصين محافظة الاسماعيلية. تم اعداد هذة التجربة لتقييم تاثير فترات الرى المختلفة وفاثيلات البوتاسيوم والتفاعل بينهم على النمو وعدد النورات ومحصول الثمار وكفاءة استخدام المياه وانتاج الزيت الطيار خلال موسمين متتاليين (٢٠١٦/ ٢٠١٧&٢٠١٧/٢٠١٨). العامل الرئيسى هو أستخدام ثلاث مستويات رى المستوى الاول هو المعدل الشائع فى هذة المنطقة وعادة يتم استهلاك كمية مياه تقدر ب ١١٥٠ مترمكعب للهكتاراما فى حالة المستوى الثانى تم استهلاك٧٦٦مترمكعب للهكتار فى حين فى حالة المستوى الثالث بلغ معدل استهلاك المياة ٣٨٣ مترمكعب للهكتار. وقد استخدم فاثيلات البوتاسيوم بتركيزات (صفر,٤٠٠ ,٥٠٠, ٦٠٠ جزء فى المليون) لتمثل العامل تحت الرئيسى. تم الحصول على اعلى نمو خضرى وكذلك محصول ثمار على النبات وانتاج للزيت الطيار من التفاعل بين فاثيلات البوتاسيوم بتركيز ٦٠٠ جزء فى المليون والرى كل ثلاثة ايام وذلك فى كلا الموسمين. وفيما يتعلق بتركيز العناصر الكبرى والصغرى فى الثمار اظهرت النتائج أن زيادة فترات الرى أدت الى زيادة تركيز العناصر الكبرى والصغرى فى الثمار. وبالنسبة لكفاءة استخدام المياة وقد لوحظ انه كلما قلت كمية المياة المستهلكه كلما زادت كفاءة استخدام المياة.كما اوضح تحليل مكونات الزيت الطيار لنيات الشمر ان مركب الميثيل شافيكول هو المكون الاساسى فى الزيت .كما ادى التفاعل بين فاثيلات البوتاسيوم بتركيز ٦٠٠ جزء فى المليون مع الرى كل ثلاثة ايام الى الحصول على اقل نسبة للميثيل شافيكول فى الزيت الطيار.وتم الاستنتاج أن زيادة الفترة بين الريات ادت الى زيادة تحمل النبات للاجهاد وذلك من خلال زيادة كفاءة استخدام المياة وكذلك زيادة تركيز العناصر الغذائية فى الثمار.