The Future of Horticulture

FSA

Article

Water Stress Depression by Foliar Applied Organic Acids on Fennel Grown in Sandy Soil

Salwa S. S. Awad Alla[1]; Sarah N. Abd El-Khalek[1,*]; Mohamed Abd El-Kawy Abd El-Sayed[1] and Mohamed Mohamoud Ibrahim Afifi[2]

[1]Medicinal and Aromatic Plants Res. Dept., Horticulture Research Institute, Agricultural Research Center, Giza, **Egypt**.

[2]Agricultural Microbiology Research Department, Soils, Water and Environment Research Institute, Agriculture Research Center, Giza, **Egypt**.

[*]**Corresponding author:** sarahnagy@arc.sci.eg

CrossMark

Future Science Association

Available online free at
www.futurejournals.org

Print ISSN: 2692-5826

Online ISSN: 2692-5834

DOI:
10.37229/fsa.fjh.2023.12.31

Received: 25 November 2023
Accepted: 20 December 2023
Published: 31 December 2023

Abstract: Fennel (*Foeniculum vulgare* Miller.) in an important medicinal and aromatic fruits used in nutrition pharmaceutical industries. The main objective of this investigation was to elucidate the influence of ascorbic and salicylic acids on optimizing growth and yield performance of fennel grown under three different irrigation levels (60, 80 and 100%) based on ETc during two seasons of 2021 and 2022. Growth characteristics (plant height, shoot number, fresh and dry weight) were found to be highest at 100 or 80% ETc and 300 ppm ascorbic acid. While, they found to minimize with 60% ETc and 100 ppm salicylic acid. Besides, different yield performance parameters such as 1000 fruit weight, fruits and essential oil yield were also significantly influenced by irrigation levels and organic acid application. Maximum results found to be 9.73 and 10.41 g for thousand fruits weight, 2.10 and 2.05 ton for fruits yield per feddan and 52.59 and 53.20 litter for essential oil yield per feddan which were recorded with irrigation level 100% ETc and 300 ppm ascorbic acid in the two seasons, respectively. Followed by 80% ETc with same rate of ascorbic acid. Antioxidant activity and total phenols increased significantly by increasing in water stress.

Key words: Water stress; Salicylic acid; Ascorbic acid; Fennel.

1. Introduction

Fennel (*Foeniculum vulgare* Miller) belongs to family Apiaceae. It is an annual plant that is cultivated for its economic, aromatic and medicinal value. Fennel fruits contain 3.5 - 5% volatile oil. Anethole and fenchone represent the main active ingredients in fennel oil. The fruits contain about 9.5% protein, 10.0% fat, 42.3% carbohydrates, 18.5% fibre and 13.4% minerals which add a nutritional value for fennel fruits. Essential oil is involved in many pharmaceutical purposes and food industry **(Badran *et al.*, 2016)**.

Water stress has a negative effect on the development of plants. It is expressed in the rate of vegetative growth, flowering, fruits set and yield. However, it has positive effect on secondary metabolites.

In contrast to well-watered plants, water stress accumulates relatively higher concentrations of metabolites like phenols, terpenes, and essential oils. The metabolic pathways that are in responsible for the synthesis and concentration of secondary metabolites that accumulate in aromatic and medicinal plants are also directly impacted by stress. Research indicates that the production and concentration of secondary metabolites vary dramatically depending on the kind and severity of drought. By promoting the expression of matching genes and activating the essential enzymes involved in the biosynthesis and accumulation of metabolic compounds, an appropriate degree of water stress may facilitate the synthesis and accumulation of active compounds. It has been reported that in some cases, severe stress causes a significant reduction in both the synthesis and concentration of the secondary metabolites. As a result, moderate water stress is ideal for active ingredient accumulation as well as suitable for increasing their concentration. **Shil and Dewanjee (2022).**

Salicylic acid (o-hydroxybenzoic acid) regulates a variety of physiological and metabolic reactions in plants, it can protect them from abiotic stress. It aids in regulating the resistance of plants to water stress. It is regarded as an endogenous phenolic growth regulator, which is generally produced in very small amounts by plants. Additionally, it regulates several physiological functions of plants, including as photosynthesis, enzyme activity, and plant development. Salicylic acid used directly promoted plant growth and development. **(Khandaker *et al.*, 2011).**

The production of several hormones, flavonoids, and other developing processes, as well as plant growth, cell division, cell wall expansion, and gene expression, are all influenced by ascorbic acid. It is a major antioxidant that is elevated in plants as a defense strategy against environmental stressors like drought. In order to counteract oxygen radicals, ascorbic acid is also a crucial part of the system of plant antioxidants that detoxify H_2O_2. (**Saha *et al.*, 2020).**

The current study was conducted examine the influence of ascorbic and salicylic acids on irrigation water productivity and yield performance of fennel grown under different water levels in sandy soil.

2. Materials and Methods

2.1. Experimental site

The current study was carried out for two seasons (2020/2021 and 2021/2022) at South Tahrir Experimental Farm, Horticulture Research Station, El-Bustan area, Egypt (latitude 33°30' 1.4"N, longitude 30°19' 10.9"E and altitude 21 m above sea level).

Treatments

Irrigation levels (I)

1. 60% crop evapotranspiration (ETc) I1
2. 80% crop evapotranspiration (ETc) I2
3. 100% crop evapotranspiration (ETc) I3

Foliar application of organic acid (OA)

1. Control (without spraying organic acid)
2. Salicylic acid at rate 100 ppm (SA1)
3. Salicylic acid at rate 200 ppm (SA2)
4. Salicylic acid at rate 300 ppm (SA3)
5. Ascorbic acid at rate 100 ppm (AA1)
6. Ascorbic acid at rate 200 ppm (AA2)
7. Ascorbic acid at rate 300 ppm (AA3)

After the plants were established, irrigation treatments were started every two days. After sowing, the first foliar application was applied 30 days later, and it was then repeated every 21 days until flower buds formed.

2.2. Design of the experiment

This experiment was set up in a split plot design with three replicates. The main plots (I) were irrigation levels included three levels, while organic acids treatments occupied the sub plots (OA) included seven treatments, thus the interaction treatments (I×OA) were twenty-one treatments.

The fruits of Indian fennel (*Foeniculum vulgare* var. *vulgare*) were obtained from Agricultural Research Station in Assiut. Fennel fruits were sown on October $20^{th,}$ for both seasons, at distances of 25 cm between hills, using surface drip irrigation system with built in drip line emitter (GR) at 25 cm spacing with manufacturing discharge 4 L/hr and crop rows with 75 cm distance between each other. With row width 50 cm. The plants were thinned forty days later to one plant/hill.

Chemical fertilizers, ammonium nitrate (33% N), calcium superphosphate (15.5% P_2O_5) and potassium sulfate (48% K_2O), were added at the recommended level as well as other cultural practices until the harvest date.

2.3. Crop-soil-water relationship

1- Reference evapotranspiration (ETo)

ET_o values were estimated relied on the local agro-meteorological data of the study site (Table 1) according to the modified Penman equation **(FAO, 1977).**

The ET_o values (in mm day^{-1}) were 4.85, 3.64, 2.42, 2.37, 3.25, 4.26, and 5.87 for October, November, December, January, February, March, and April, respectively, May has been excluded. The form of Penman equation as following:

$$\mathbf{ETo = c\ [\ W\ .\ Rn + (1\text{-}W).\ f\ (u)\ .\ (ea\text{-}ed)]}$$

Where:

ETo = reference crop evapotranspiration in mm/day.

W= ttemperature-related weighting factor.

Rn = net radiation in equivalent evaporation in mm/day.

F(u)= wind-related function.

(ea-ed) = ddifference between the saturation vapor pressure at mean air temperature and the mean actual vapour pressure of the air both in mbar.

C = Adjustment factor to compensate the effect of day and night weather condition.

Climatic factors during the experimental period were collected from weather station allocated at the experimental location and are shown in Table 1.

2.4. Crop evapotranspiration (ETc)

The ETc values were calculated according to the following equation given by **FAO (1977):**

$$\mathbf{ETc = Kc\ .\ ETo}.$$

Where:

ETc: crop evapotranspiration (mm day^{-1}).

Kc: crop coefficient.

ET_o: reference crop evapotranspiration (mm day^{-1}).

Table (1) agro-meteorological data at the site during 2020/2021 and 2021/2022 seasons

Month		Season 2020/2021						
		October	**November**	**December**	**January**	**February**	**March**	**April**
Temperature ℃	**Max**	27.88	21.02	17.94	19.90	22.35	27.00	36.74
	Min	15.95	11.69	7.02	8.07	9.97	12.73	22.73
RH-AVG%		58.64	57.73	65.50	58.44	61.43	58.93	49.23
Wind speed (m/sec)		2.82	2.50	3.31	3.37	2.82	3.12	3.24
Radition ($MJ/m^{2)}$		18.12	14.78	13.01	11.66	14.82	19.22	25.14
Et_0 mm day^{-1}		4.85	3.64	2.42	2.37	3.25	4.26	5.87
		Season 2021/2022						
Temperature ℃	**Max**	26.51	22.25	19.13	20.78	24.57	29	38.4
	Min	13.83	13.2	8.91	8.85	11.67	14.14	25.34
RH-AVG%		57.67	56.53	66.41	56.63	62.51	60.58	50.02
Wind speed (m/sec)		2.54	2.21	3.37	3.52	2.88	3.44	3.27
Radition ($MJ/m^{2)}$		19.23	19.23	19.23	19.23	19.23	19.23	19.23
Et_0 mm day^{-1}		4.65	3.86	2.64	2.45	3.37	4.18	5.54

2.5. Applied irrigation water (AIW)

The amounts of applied irrigation water were calculated according to the equation given by **Vermeiren and Jopling (1984)** as follows:

$$\text{AIW} = \frac{\text{ETc x I}}{\text{Ea }(1-\text{LR})}$$

Where:

AIW: depth of applied irrigation water (mm).

ETc: crop evapotranspiration (mm day^{-1}).

I: irrigation interval (days).

Ea: irrigation application efficiency for the drip irrigation system (≈ 90% at the experimental site).

LR: leaching requirements: the extra amount of applied water needed for salt leaching, calculated according to **FAO (1985)** as follows:

$\mathbf{LR = ECiw/ECe}$ where ECiw (dS/m): EC of irrigation water. ECe (dS/m) of soil extract.

2.6. Irrigation water productivity (IWP)

Irrigation water productivity (IWP) describes the efficiency of the water applied in yield production. It is determined as described by **Jensen (1983)** as follows:

$$\text{IWP}(\text{kg m}^{-3}) = \frac{\text{Yield }\left(\frac{\text{kg}}{\text{fadan}}\right)}{\text{Seasonal AIW }\left(\frac{\text{m}^3}{\text{fadan}}\right)}$$

The physical and chemical characterizes of the used soil were determined according **Yancy *et al.*, (1982)** are shown in Table 2.

Table 2. Chemical and physical analysis of the soil at experimental field

Physical properties	
Soil layer depth (cm)	0-30
Texture	Sandy
Course sand (%)	48.66
Fine sand (%)	48.83
Silt+ clay (%)	2.51
Field Capacity, (%)	13.0
Wilting Point, (%)	4.6
Available water, (%)	8.4
Bulk density (t m^{-3})	1.69
Chemical properties	
$EC_{1:5}$ (dS m^{-1})	0.45
pH (1:2.5)	8.60
Total $CaCO_3$ (%)	7.00

The chemical analysis of the well irrigation water is shown in Table 3.

Table 3. Chemical properties of well water

pH	**ECw**		**Mill equivalent/liter**						
			Cations				**Anions**		
	ppm	**dS/m**	**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**Cl^{-}**	**CO_3^{--}**	**HCO_3^{-}**
7.78	1664	2.60	4.00	3.60	18.01	0.32	17.20	-	5.20

Fennel plants were harvested in 5th May for the first season and 9th May for the second season.

2.7. Growth characteristics

Growth characteristics recorded werethe plant height (cm), number of shoots/plant, dry weight/plant.

2.8. Crop yield characteristics

Crop yield characteristics were biological yield, fruit yield/plant (g) and per feddan (ton) as well as the harvest index was calculated using the following formula: Harvest index (%)= Economic yield/biological yield × 100.

2.9. Essential oil productivity

Essential oil content was carried out according to the method of **ASTA (1985).** Oil yield/plant (ml) and oil yield/fed. (l) were also determined.

GC/MS Analysis of Essential oil: The GC-MS system was equipped with gas chromatograph (7890B) and mass spectrometer detector (5977A), according to **(Adams, 2007).**

The phenolic content was determined as mg of gallic acid equivalents (GAE) per fennel fruits dry matter **(Tupe *et al.*, 2013).** The method of **Kang *et al.*, (2011)** was used to assay the DPPH radical scavenging activity

2.10. Statistical analysis

The COSTAT statistical program was utilized to do an analysis of variance (ANOVA) on the significant differences observed between the treatments. The least significant difference (L.S.D.) test was used to assess the differences in treatment means at a probability level of 0.05 **(Steel and Torrie, 1980).**

3. Results and Discussion

3.1. Rreference evapotranspiration (ET_o/mm.day^{-1}), crop coefficient and crop evapotranspiration (ETc mm.day^{-1})

The irrigation water requirements for fennel plants during both studied seasons; were calculated by computing the estimated reference evapotranspiration (ETo) using the Penman- Monteith equation as the standard procedure described in FAO. Data in Table (4) showed that the ETc (irrigation water requirements) where the quantity of irrigation water increased gradually with the present increase in the plant age during two growth seasons. It can be clearly seen that significantly during the month of March it was achieved the highest values which it was 152 and 149 mm/month during both seasons respectively. The limitation requirement of irrigation water for plants is a point very important for cultivating crops or not. The scheduling irrigation according to weather factors should be appropriate and the principles of deficit irrigation should be accepted with a simple level of reduction in yield. Deficit irrigation is very useful and important for increasing water productivity in view limitation of water resources in agriculture. So, the requirement of irrigation water its considered the main point in scheduling the irrigation program **(El-Gamal *et al.*, 2021).**

Table (4). Rreference evapotranspiration (ET_o/mm), crop coefficient and crop evapotranspiration for the full irrigation treatment (100% of ET_C) during 2020/2021 and 2021/2022seasons

Month	Season 2020-2021				Season 2021-2022		
	Days	ETo (mm/month)	Kc	ETc (mm/month)	ETo (mm/month)	Kc	ETc (mm/month)
October	10	4.85	0.35	17	4.65	0.35	16
November	30	3.64	0.35	38	3.86	0.35	39
December	31	2.42	0.75	56	2.64	0.75	61
January	31	2.37	1.15	84	2.45	1.15	87
February	28	3.25	1.15	105	3.37	1.15	109
March	31	4.26	1.15	152	4.18	1.15	149
April	30	5.87	0.45	79	5.54	0.45	75

3.2. Applied irrigation water (AIW)

Data in Table (5) showed that the periodically (month) irrigation water applied values initially was low in fist stage with lower temperature, then increased gradually to reached the highest values with plant development in March (283, 378, 472 and 567 m^3 with irrigation levels respectively) then, slightly declined with maturity stage till harvest period. Generally, seasonally applied irrigation water obtained 933, 1323 and 1654 m^3 fad^{-1} with irrigation levels 60, 80 and 100% from ETc respectively. The results were harmony with **Serag El-Din and Mokhtar (2020).** they found the results proved that, irrigation water applied and water consumptive use were increased with the increase in the amount of irrigation.

3.3. Characteristics of vegetative growth

The results of Fennel growth characteristics as affected by irrigation levels and foliar application during two successive seasons are shown in Table (6)

Results in Table (6) indicate proportional decrease in all growth characteristics i.e. (plant height, shoots number and dry weight of plant) with the decrease irrigation levels in both seasons. Irrigation level 100% ETc recorded the highest values of plant height (155.71 and 157.42 cm), shoots number (11.97 and 13.07), dry weight of plant (451.26 and 453.38 g) in both seasons. followed by 80%ETc. The highest reduction of plant growth parameters was recorded with 60% ETc which as it gave the lowest values of plant height (137.08 and 139.97 cm), shoot number (8.70 and 9.41) and plant dry weight (369.58 and 366.22 g) in both seasons.

Table (5). Seasonal applied irrigation water to fennel crop during 2020/21 and 2021/22 seasons

Month	First season			Second season		
	Irrigation levels m^3/month			Irrigation levels m^3/ month		
	I_1	I_2	I_3	I_1	I_2	I_3
October	32	42	53	29.87	39.82	49.78
November	71	95	119	72.8	97.07	121.3
December	105	140	175	113.9	151.8	189.8
January	158	210	263	162.4	216.5	270.7
February	195	260	326	203.5	271.3	339.1
March	283	378	472	278.1	370.8	463.6
April	148	197	247	140	186.7	233.3
Seasonal	**993**	**1323**	**1654**	**1001**	**1334**	**1668**

***I1=60% ETc, I2=80% ETc, I3= 100 ETc.**

Our findings are consistent with those of **Corell *et al.* (2012)** on *Salvia officinalis*, **Bahreininejad *et al.* (2013)** on thyme, **Mehanna *et al.* (2015)** on coriander who found that increasing water stress from 50% to 100% of ETc increased plant growth.

The significant impact of raising irrigation levels to 100% ETo on plant development may be attributed to the promotion of cell division and enlargement, both of which require greater water availability. **(Hammad, 1991).**

The primary reason of stem length loss is typically a decrease in the leaching fraction, which results from less water being accessible in the active root zone. This disruption of the physiological processes necessary for plant growth is what causes the stem height to decrease. **(Ahmadi-Mirabad *et al.*, 2014).** Additionally, it's possible that water stress causes significant reductions in plant growth and development, which in turn impacts cell turgor, volume, elongation and division rates, stem and cell growth, and ultimately, shoot height. **(Farooq *et al.*, 2009).** The plant's cell walls and cells shrink as its water content decreases.

Low soil moisture levels may have inhibited plant growth by reducing the absorption of nutrients, which in turn may have deterred physiological processes essential for plant growth. When ABA content rises, stomatal conductance decreases, which at the same time shrinks all of the plant's developing vegetative organs. **(Alobaidy, 2017).**

The efficacy of Ascorbic and salicylic acid in reducing the harmful effect of water deficiency on growth characteristics indicate in Table (6). all concentrations of SA have low efficacy on growth characteristics compared to AA under different irrigation levels. while, plants treated with AA3 (300 ppm) produced highest values of plant height (166.63 and 169.39 cm), number of shoots (13.46 and 14.68 shoots/plant), dry weight g/plant (465.48 and 456.09 g/plant) in two seasons, respectively, compared to in the control and the other treatments.

Therefore, increased plant antioxidant capacity as well as cell division and expansion may have contributed to the growth enhancement caused by AA treatment. **(Athar *et al.* 2008)**. **Zhang (2013)** showed that, even in the best of circumstances, ascorbate and the enzymes that manufacture and metabolize it are strongly related to the processes of cell wall metabolism and cell proliferation, gene expression, defiance regulation, and survival.

The effect of interaction between irrigation levels and foliar application on plant height was significant in both seasons as shown in Table (6). Irrigation with 100 % ETc level interacted with Ascorbic acid (300 ppm) foliar application gave the highest plant height 172.67 and 175.10 cm, shoot number 15.48 and 16.64 shoot/plant, dry weight/plant 506.79 in 497.95 g the 1st and 2nd seasons, respectively). Followed by 80% ETc interacted with AA (300 ppm) with mean values of plant height

169.33 and 171.02 cm, shoot number 13.89 and 15.42 shoot/plant and dry weight per plant 479.12 and 475.78 g/plant. The differences between these treatments were non-significant. The shortest plants (107.21 and 109.35 cm), the minimum number of shoots (5.74 and 6.20 shoot/plant) and the lowest dry weight/plant (300 and 314.45 g/plant) in both seasons, were recorded with 60 % ETc and control (untreated plants).

These results are similar to those reported by **Azooz and Al- Fredan (2009)** for *Vicia faba* plants. Ascorbic acid has a growth-promoting effect on plants that may be explained by enhancing the availability and uptake of water and vital nutrients by modifying cell osmotic pressure, as well as by decreasing the build-up of dangerous free radicals (ORS) by boosting antioxidant and enzyme activity. **(Farouk *et al.*, 2011).** Furthermore, as was discovered in the current study, ascorbic acid may have a beneficial influence on plant growth by increasing nutrient intake and elements content, such as potassium, phosphorous, and nitrogen. Both potassium and phosphorus are vital minerals that are required for cell division, cell turger, and the production of DNA and RNA. They also play a significant role in the manufacture and translocation of carbohydrates. **(Saeidi-Sar *et al.*, 2013)**.

Table (6). Effect of irrigation levels and organic acids rates on vegetative growth Characteristics of fennel during 2020/2021 and 2021/2022 Seasons

Plant height (cm)								
Organic acid (OA)	First season				Second season			
	Irrigation levels				Irrigation levels			
	I1	I2	I3	Mean	I1	I2	I3	Mean
Control	107.21	116.43	124.13	**115.92**	109.35	119.76	126.62	**118.58**
SA1	122.58	126.44	145.71	**131.58**	125.03	130.97	148.62	**134.87**
SA2	136.02	140.59	154.84	**143.82**	138.74	144.40	149.94	**144.36**
SA3	141.99	149.25	165.53	**152.26**	144.83	159.24	167.78	**157.28**
AA1	143.33	153.53	160.41	**152.42**	146.20	156.60	163.61	**155.47**
AA2	150.57	164.03	166.67	**160.42**	153.58	168.31	170.26	**164.05**
AA3	157.88	169.33	172.67	**166.63**	162.06	171.02	175.10	**169.39**
Mean	**137.08**	**145.66**	**155.71**		**139.97**	**150.04**	**157.42**	
LSD (0.05)	**I= 3.11 OA= 2.03 I*OA= 4.55**				**I= 4.22 OA= 2.12 I*OA=5.18**			
Number of shoots								
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	5.74	6.77	6.94	**6.48**	6.20	7.32	8.50	**7.34**
SA1	7.39	8.20	9.55	**8.38**	7.98	8.85	10.31	**9.05**
SA2	8.02	9.61	11.13	**9.59**	8.66	10.38	12.02	**10.35**
SA3	8.98	12.37	14.94	**12.10**	9.70	13.20	15.89	**12.93**
AA1	9.60	10.25	12.76	**10.87**	10.37	11.07	13.78	**11.74**
AA2	10.19	11.65	13.00	**11.61**	11.00	12.58	14.33	**12.64**
AA3	11.01	13.89	15.48	**13.46**	11.97	15.42	16.64	**14.68**
Mean	**8.70**	**10.39**	**11.97**		**9.41**	**11.26**	**13.07**	
LSD (0.05)	**I= 1.32 OA= 0.87 I*OA=1.77**				**I= 1.17 OA= 0.93 I*OA=1.45**			
	Dry weight (g/plant)							
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	300.00	313.21	365.80	**326.34**	314.45	321.38	343.85	**326.56**
SA1	363.45	387.23	419.10	**389.93**	345.65	374.77	432.45	**384.29**
SA2	370.46	422.98	459.34	**417.59**	382.33	418.04	472.29	**424.22**
SA3	383.84	444.75	471.14	**433.24**	393.78	450.14	483.41	**442.44**
AA1	368.21	421.65	449.19	**413.02**	359.67	420.74	463.84	**414.75**
AA2	390.59	454.23	487.44	**444.09**	373.12	448.68	479.86	**433.89**
AA3	410.54	479.12	506.79	**465.48**	394.54	475.78	497.95	**456.09**
Mean	**369.58**	**417.60**	**451.26**		**366.22**	**415.65**	**453.38**	
LSD (0.05	**I= 16.15 OA=10.54 I*OA=28.15**				**I= 12.27 OA= 7.71 I*OA=24.43**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

3.4. Fruits weight (g/plant) and fruit yield (ton/Feddan)

Irrigation levels significantly affected fruits weight (g/plant) and yield (ton/feddan) as shown in Table (7) for both seasons. Irrigation at 100% ETc significantly increased seeds weight (g/plant) and yield (ton/feddan) comparing to 80% and 60% ETc in both seasons. It is clear that the application of 100% ETc level of water irrigation was superior for seeds yield (ton/feddan) in both seasons.

The maximum values of fruits weight (126.59 and 131.33 g/plant in 1st and 2nd seasons, respectively) and maximum fruits yield (1.65 and 1.71 ton/feddan in the first and second seasons, respectively) were resulted from plants irrigated at 100 % ETc. On the other hand, plants irrigated at 60 % ETc produced the minimum values of fruits weight (90.07 and 96.59 g/plant in 1st and 2nd seasons, respectively) and minimum fruits yield (1.17 and 1.26 ton/feddan in the first and the second seasons, respectively).

In well-watered conditions, photosynthesis rate and assimilates production are increased which consequently resulted in the elevation of fruits yield through increasing in fruits filling rate and fruits weight**.** On the other hand, it appears that the reduced fruit production values seen in the case of 60% ETc may be caused by occasional water application, which leaves the active crop root zone dry, insufficient moisture conservation, and poor nutrient use. **(Ahmadi-Mirabad *et al.*, 2014).**

The reduction effect of water stress on seeds yield may be due to many reasons reported by many researchers, showed that excessive moisture stress during the reproductive stage caused reduced seed output and subjected the plant to floral abortion. Also, a low irrigation frequency was caused by a shortage of nutrients rather than water, and a high irrigation frequency may make up for this. Because photosynthesis and plant biomass are reduced in situations of increasing water stress, seed output is decreased. **(Ghassemi-Golezani *et al.*, 2017).** These results take the same trend with those of **Mehanna *et al.* (2015)** on coriander and **Mehta *et al.* (2011)** on fennel.

Foliar application showed significant effect on fruits weight and yield of fennel in both seasons (Table, 7). Data showed that salicylic acid affected fruits weight (g /plant) and yield (ton/feddan) significantly in the first season and the second season.

All concentrations of salicylic acid foliar application comparing to control increased fennel fruits weight (g) and yield (ton) significantly in both seasons. Spraying salicylic acid at 300 ppm had a significantly effect on fruit weight (117.52 and 121.94 g/plant) and fruits yield/feddan (1.53 and 1.58 ton/fed.) compared to the control (fruits weight/plant 63.79 and 77.60 g/plant) and (fruits yield 0.83 and 1.01 ton/fed.).

These increases in fruits may be the result of physiological mechanisms stimulated by salicylic acid, which improved vegetative development and subsequently caused active translocation of photosynthetic products from source to fruits. Similarly, of salicylic acid results were obtained by **Hussein *et al.* (2015)** on canola.

Regarding the effect of ascorbic acid (AA), it was noticed in general that the plants which were treated by 100, 200 and 300 ppm showed significant increase in the fruit weight g/plant in the two seasons. In the first season data were 113.29, 126.70 and 140.44 g/plant compared to untreated plants (control) with mean value 63.79 g/plant. The same trend was found in the second season *i.e.* fennel plants showed good response to ascorbic acid at the three rates used and produced the highest fruit weight/plant 119.07 g for 100 ppm, 127.05 g for 200 ppm and 136.63 g/plant for 300 ppm compared to control 77.60 g/plant.

The most effective foliar application in fruits weight and fruit yield/fedaan production was Ascorbic acid with 300 ppm which gave the extremely high values of fruits weight and yield (140.44 g and 1.83 ton, respectively) in the first season. Whereas, in the second season (136.63 g and 1.78 ton, respectively).

These findings concurred with those of **El-Gabas (2006),** who discovered that ascorbic acid spraying increased sunflower production. **Ali, *et al.*, (2017)** discovered that applying ascorbic or salicylic acid enhanced fennel yield. **Mohamed *et al.*, (2022)** showed that growth stimulant substances increased fruits yield of fennel to amounted 2.33 ton/fed.

Results shown in Table (7) pointed out that, the interaction effect was significant in both seasons. The fruits weight and yield per feddan of fennel plant ranged from 54 to 161.83 g/plant; 0.70 to 2.10 ton/feddan in the first season and from 71.40 to 157.41 g/plant and 0.93 to 2.05 ton/fed. in the second season.

Evidently, the greatest fruits weight per plant and yield per feddan of fennel (161.83 and 157.41 g/plant; 2.10 and 2.05 ton in the 1st and 2nd season, respectively) were resulted from plants irrigated at 100% ETc combined with ascorbic acid 300 ppm foliar followed by (152.17 and 141.02 g/plant; 1.98 and 1.83 ton in 1st and 2nd season, respectively) from plants irrigated at 80% ETc combined with ascorbic acid 300 ppm.

The lowest fruit weight and yield (54 g and 0.70 ton) were recorded with application of 60% ETc with control (tap water) in the first season and (71.40 g and 0.93 ton) in the second season.

Table (7). Effect of irrigation levels and organic acids rates on fruits productivity of fennel during 2020/2021 and 2021/2022 Seasons

Organic acid (OA)	Fruits yield/plant (g)							
	First season				Second season			
	Irrigation levels (I)				Irrigation levels (I)			
	I1	I2	I3	Mean	I1	I2	I3	Mean
Control	54.00	62.16	75.20	**63.79**	71.40	75.05	86.34	**77.60**
SA1	88.17	101.97	114.04	**101.39**	90.51	98.80	119.07	**102.79**
SA2	90.21	113.68	126.90	**110.26**	100.82	114.78	132.49	**116.03**
SA3	98.85	122.93	130.77	**117.52**	105.16	124.12	136.54	**121.94**
AA1	92.75	118.04	129.08	**113.29**	96.34	121.60	139.27	**119.07**
AA2	99.18	132.62	148.30	**126.70**	100.47	132.51	148.18	**127.05**
AA3	107.31	152.17	161.83	**140.44**	111.46	141.02	157.41	**136.63**
Mean	**90.07**	**114.80**	**126.59**		**96.59**	**115.41**	**131.33**	
LSD (0.05)	**I=5.87 OA= 2.51 I*OA= 6.59**				**I=6.19 OA= 2.11 I*OA=8.42**			
	Fruits yield/fed. (ton)							
	I1	I2	I3	Mean	I1	I2	I3	Mean
Control	0.70	0.81	0.98	**0.83**	0.93	0.98	1.12	**1.01**
SA1	1.15	1.33	1.48	**1.32**	1.18	1.28	1.55	**1.34**
SA2	1.17	1.48	1.65	**1.43**	1.31	1.49	1.72	**1.51**
SA3	1.29	1.60	1.70	**1.53**	1.37	1.61	1.77	**1.58**
AA1	1.21	1.53	1.68	**1.47**	1.25	1.58	1.81	**1.55**
AA2	1.29	1.72	1.93	**1.65**	1.31	1.72	1.93	**1.65**
AA3	1.40	1.98	2.10	**1.83**	1.45	1.83	2.05	**1.78**
Mean	**1.17**	**1.49**	**1.65**		**1.26**	**1.50**	**1.71**	
LSD (0.05)	**I= 0.16 OA= 0.08 I*OA= 0.28**				**I=0. 22 OA= 0.04 I*OA=0.24**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

3.5. Biological yield (ton fed.$^{-1}$)

Biological yield of fennel is the total biomass weight of the crop including straw, grain and the results on this trait as influenced by various irrigation levels and foliar application for both seasons are presented in Table (8). The biological yield fennel was significantly affected due to irrigation levels, foliar application as well as by their interaction. The data indicated that 100% and 80% ETc, resulted in significantly maximum biological yield 5.87 and 5.43 ton fed^{-1} in the first and second seasons, respectively. While the minimum biological yield (4.81 and 4.76 ton fed^{-1} in both seasons, respectively) was recorded in 60% ETc.

The application of SA and AA resulted in a considerable increase in plant biological yield compared to control plants. Foliar application of SA led to a significant increase in biological yield (ton/fed^{-1}) with mean values 5.07 ton for 100 ppm, 5.43 ton for 200 ppm and 5.63 ton for 300 ppm in the first season. While, in the second season 5.00, 5.51 and 5.75 ton fed^{-1} for same concentrations respectively. The application of ascorbic acid (AA) resulted in some improvement in biological yield as compared with control. The data indicated that AA 300 ppm, resulted in significantly maximum biological yield (6.05 and 5.93 ton fed^{-1} in the first and the second season, respectively). It is noted that there are no significant differences between the medium concentration of ascorbic acid (200 ppm) and the high concentration of salicylic acid (300 ppm). The study of **Ali *et al.*, (2017)** on fennel plants indicated that application of ascorbic acid diminished the injurious effects of terminal drought stress and increased biological yield of plants significantly.

Interaction between irrigation levels and foliar application affected biological yield significantly in both seasons. Maximum biological yield 6.59 and 6.47 ton fed^{-1} in the first and the second seasons, respectively was recorded with foliar application of combination of AA at rate 300 ppm under 100 % ETc., followed by 80% ETc with same rate of AA (300 ppm). Minimum biological yield (3.90 and 4.09 ton $fed.^{-1}$ in both seasons) was recorded under irrigation level 60% ETc with control (tap water spray). These findings are consistent with those of **Kalamian *et al.* (2006)**, who similarly found that conditions of water deficiency decreased maize's biological yield. It was also reported by **Gahory *et al.* (2022)** that foliar application of ascorbic acid increased biological yield of coriander.

3.6. Harvest index (%)

The harvest index is the percentage of grain from the biological yield obtained from a unit area. The effect of irrigation treatments, foliar application treatments and their interaction on harvest index of fennel plants in both seasons are shown in Table (8). It is observed from the data that harvest index was highest (27.75 and 28.78% in both seasons) in plots receiving irrigation levels 100% ETc, followed by the crop receiving 80 % ETc with harvest index of 27.11 and 27.52% in the first and the second seasons, respectively. No significant difference was detected between the harvest index by crop irrigated at 80% or 100% ETc., while the lowest harvest index of 24.19 and 26.30% in the both seasons was noted in irrigation levels 60% ETc. The results are supported by **Mehta *et al.* (2011)** on fennel and **Ahmed *et al.*, (2021)** on sunflower.

In foliar application treatments, the highest harvest index (29.96 and 29.84% in the both seasons) was noted in foliar application with 300 ppm ascorbic acid, followed by ascorbic acid at rate 200 ppm with harvest index of 28.33 and 29.15% in the both seasons; while the lowest harvest index of 19.48 and 23.75% was observed in control (tap water). on the other hand, high concentration of Salicylic Acid (300 ppm) affected significantly on harvest index (27.10 and 27.49% in the both seasons) comparing to control. These results are in conformity with findings reported by **Ali *et al.*, (2017)** on fennel.

The interaction between "100% ETc and AA at rate 300 ppm" resulted in maximum harvest index of 31.87% and 31.68% in the first and the second seasons, followed by 80% ETc and AA at rate 300 ppm with harvest index of 31.78 and 29.56% in both seasons. while the interaction between "60% ETc and control" resulted in minimum harvest index of 17.95% and 22.74% in the both seasons.

3.7. Irrigation water productivity (IWP, kg m^{-3})

The results in Table (9) shows that irrigation water productivity with 60% or 80% of ETc gave the maximum value otherwise, productivity for fennel plants increased with increased irrigation levels but consumption water unit in production was more efficient when used level of 60% then 80% from ETc where its recorded 1.18, 1.13, 1.26 and 1.12 kg/m^3 during two seasons respectively. Therefore, reduced rate in yield was lower than the reduced rate in irrigation water which means the losses in water irrigation were higher with the levels 100% from others. In other words, level 60% of irrigation water was completely consumed with increased production and lower losses, Also, water use efficiency was higher in treatments 60 and 80% ETc with the highest concentrations of salicylic and ascorbic acids during two growth seasons respectively.

Table (8). Effect of irrigation levels and Organic acids rates on biological yield/fed. (ton) and harvest index of fennel during 2020/2021 and 2021/2022 seasons

	Biological yield/fed. (ton)							
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	3.90	4.07	4.76	**4.24**	4.09	4.18	4.47	**4.25**
SA1	4.72	5.03	5.45	**5.07**	4.49	4.87	5.62	**5.00**
SA2	4.82	5.50	5.97	**5.43**	4.97	5.43	6.14	**5.51**
SA3	4.99	5.78	6.12	**5.63**	5.12	5.85	6.28	**5.75**
AA1	4.79	5.48	5.84	**5.37**	4.68	5.47	6.03	**5.39**
AA2	5.08	5.90	6.34	**5.77**	4.85	5.83	6.24	**5.64**
AA3	5.34	6.23	6.59	**6.05**	5.13	6.19	6.47	**5.93**
Mean	**4.81**	**5.43**	**5.87**		**4.76**	**5.40**	**5.89**	
LSD (0.05)	**I=0.28 OA= 0.10 I*OA=0.37**				**I= 0.20 OA= 0.15 I*OA=0.32**			
	Harvest index (%)							
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	17.95	19.90	20.59	**19.48**	22.74	23.44	25.06	**23.75**
SA1	24.36	26.44	27.16	**25.99**	26.28	26.28	27.58	**26.71**
SA2	24.27	26.91	27.64	**26.27**	26.36	27.44	28.01	**27.27**
SA3	25.85	27.68	27.78	**27.10**	26.76	27.52	28.18	**27.49**
AA1	25.26	27.92	28.77	**27.32**	26.71	28.88	30.02	**28.54**
AA2	25.39	29.15	30.44	**28.33**	27.01	29.50	30.93	**29.15**
AA3	26.22	31.78	31.87	**29.96**	28.27	29.56	31.68	**29.84**
Mean	**24.19**	**27.11**	**27.75**		**26.30**	**27.52**	**28.78**	
LSD (0.05)	**I= 1.23 OA=0.67 I*OA=2.50**				**I=1.17 OA= 0.59 I*OA=2.81**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

Table (9). Irrigation water productivity (IWP, kg m^{-3}) as affected by irrigation levels and organic acids during of 2020/21 and 2021/22 seasons

Organic acid (OA)	Irrigation water productivity (IWP, kg m^{-3})							
	First season				**Second season**			
	Irrigation levels				**Irrigation levels**			
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	0.70	0.61	0.59	**0.64**	0.93	0.73	0.67	**0.78**
SA1	1.16	1.01	0.89	**1.02**	1.18	0.96	0.93	**1.02**
SA2	1.18	1.12	1.00	**1.10**	1.31	1.12	1.03	**1.15**
SA3	1.30	1.21	1.03	**1.18**	1.37	1.21	1.06	**1.21**
AA1	1.22	1.16	1.02	**1.13**	1.25	1.18	1.09	**1.17**
AA2	1.30	1.30	1.17	**1.26**	1.31	1.29	1.16	**1.25**
AA3	1.41	1.50	1.27	**1.39**	1.45	1.37	1.23	**1.35**
Mean	**1.18**	**1.13**	**0.99**		**1.26**	**1.12**	**1.02**	
LSD (0.05)	**I= 0.04 OA= 0.04 I*OA= 0.11**				**I= 0.09 OA= 0.08 I*OA=0.13**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

3.8. Thousand fruit weight (g)

The effect of irrigation treatments, foliar application treatments and their interaction on thousand fruit weight of fennel plants in both seasons are shown in Table 10. Thousand fruit weights are very important yield contributing component of every crop including fennel. As regards the effect of varying irrigation levels, the maximum thousand fruit weights 8.49 and 9.08 g were produced in 100% ETc., followed by 80% ETc with mean values of thousand fruit weights (7.67 and 8.21 g in both seasons) while, the lowest fruits weight (6.27 and 6.71 g in the both seasons) recorded in 60% ETc.

The findings support those of **Khan (2001),** who also found that irrigation levels had a significant effect on the weight of 1000 seeds. **Wang *et al.*, (2010)** who stated that raising irrigation levels can result in an increase in grain weight. **Kabir, *et al.*, (2009)** found that a significant drop in grain weight was the result of early grain desiccation brought on by water stress.

As for ascorbic and salicylic acid treatments, the recorded data in Table (10) the highest concentration of ascorbic acid (300 ppm) registered the heaviest 1000 fruit weight (8.45 and 9.05 g in the first and the second seasons, respectively). Followed by SA at rate 300 ppm with mean values of thousand fruit weights 7.79 and 8.34 g. The increase in fruits weight due to applying ascorbic acid was detected by **Ali *et al.*, (2017)** on fennel. Salicylic acid's stimulating effect in increasing fruit yield was studied by **Badran *et al*. (2013)** on coriander.

The interaction between “100% ETc and AA at rate 300 ppm” resulted in maximum fruits weight of 9.73 and 10.41 g in the first and the second seasons, respectively. While the interaction between “60% ETc and control” resulted in minimum fruits weight of 5.27 and 5.64 g in both seasons.

Table (10). Effect of irrigation levels and organic acids rates on Thousand fruits weight (g) of fennel during 2020/2021 and 2021/2022 Seasons

Organic acid (OA)	Thousand fruits weight (g)							
	First season				Second season			
	Irrigation levels (I)				Irrigation levels (I)			
	I1	I2	I3	Mean	I1	I2	I3	Mean
Control	5.27	6.58	7.46	**6.44**	5.64	7.04	7.99	**6.89**
SA1	5.61	7.14	8.10	**6.95**	6.01	7.64	8.67	**7.44**
SA2	6.17	7.85	8.24	**7.42**	6.60	8.40	8.81	**7.94**
SA3	6.70	8.14	8.54	**7.79**	7.17	8.71	9.14	**8.34**
AA1	5.78	7.66	8.35	**7.26**	6.18	8.19	8.93	**7.77**
AA2	6.94	8.10	9.00	**8.01**	7.43	8.67	9.63	**8.58**
AA3	7.41	8.22	9.73	**8.45**	7.93	8.80	10.41	**9.05**
Mean	**6.27**	**7.67**	**8.49**		**6.71**	**8.21**	**9.08**	
LSD (0.05)	**I=0.36 OA=0.20 I*OA=0.49**				**I=0.30 OA=0.19 I*OA=0.41**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

3.9. Essential oil productivity of fennel

The mean values of fennel seeds essential oil percentage of different treatments for the two successive seasons are shown in Table (11). The effect of irrigation levels on seeds essential oil percent was significant in both seasons. Irrigation level at 100% ETc significantly decreased the essential oil percent comparing to 80% ETc level with mean values 2.16% and 2.25% in both seasons. On the other hand, 60% ETc gave the lowest essential oil content 2.04% and 2.12% in both seasons. Increasing ETc levels decreased the essential oil percent, in other words water stress increased the seeds essential oil percent in both seasons. Water deficiency increased the oil percentage of medicinal and aromatic plants because in case of stress, more metabolites are produced in the plants and substances prevented from oxidization in these stressed cells. Overall, it could be expressed as tolerance mechanism towards water limited conditions **(Hossein *et al.*, 2009).**

Fennel is one of the plants that produces more EO in response to drought stress; it is well known that the biosynthesis of secondary metabolites is genetically determined. The biosynthesis of EO in fennel was found to be impacted by irrigation regimes in this study, which is consistent with the results of **Rioba *et al.* (2015)**. **GarciaCaparros *et al.* (2019)** have proposed that the increased density of oil glands during water stress could be the cause of the elevated levels of EO. In contrast, **Kleinwachter *et al*. (2015)** indicated that a decrease in the synthesis of secondary metabolites was caused by a severe drought stress. The excessive consumption of the assimilate to produce osmotic regulator chemicals may be the cause of the drop in EO content under severe drought stress.

On the other hand, essential oil yield ml/plant and l/fed. Have increased gradually with increased irrigation levels. The highest values of oil yield were recorded in 100% ETc with mean values of essential oil yield/plant (2.71 and 2.91 ml/plant) and oil yield/fed., (35.28 and 37.87 l/fed.). followed by 80% ETc with mean values 2.55 and 2.65 ml/plant, 33.14 and 34.49 l/fed., in both seasons. On the other hand, the lowest mean values were recorded 1.88 and 2.08 ml/plant, 24.44 and 27.10 l/fed., by irrigation level at 60% ETc.

Deficit in water reduced the oil yield of rosemary (*Rosmarinus officinalis* L.) and anis (*Pimpinella anisum* L.) **Singh and Ramesh (2000).**, **Zehtab-Salmasi *et al.*, (2001)** water stress decreased oil yield, but oil percentage increased, according to their findings. **Nadjafi, (2006)** found that while essential oil yield was reduced, essential oil percentage increased in *Nepeta binaludensis* when there was a water deficit.

Foliar application of all concentrations of ascorbic acid significantly affected the essential oil percentage and yield. Plants sprayed with 300 ppm ascorbic acid produced the highest content of essential oil 2.48% and 2.58% compared to control (1.53% and 1.59%) and other treatments in the two seasons, respectively. Also, the highest mean values of essential oil yield/ plant were 3.49 and 3.53 ml compared to control (0.98 and 1.24 ml/plant) and other treatments. The same direction, the highest mean values of essential oil yield /fed., 45.43 and 45.97 l, compared to control (12.71 and 16.08 l) and other treatments in the both seasons. Foliar application of 300 ppm salicylic acid to fennel plants increased essential oil percentage (2.26 and 2.35%), essential oil yield/plant (2.66 and 2.87 ml) and essential oil yield/fed., (34.58 and 37.35 l) comparing to control plants in the first and the second season, respectively. Also, the positive effects of ascorbic acid and salicylic acid in the fruit yield and its components were recorded by **Kenawy (2010)** *Ammi visnaga*; and **Ali *et al.* (2017)** on fennel.

The results of the interaction between irrigation levels and foliar application of ascorbic acid and salicylic acid showed that the superiority of 80 or 100% ETc with ascorbic acid at rate 300 ppm treatment gave the highest essential oil percentage 2.51and 2.50 in the first season. Also, in the second season 2.62 and 2.60 % and there no significant differences between these treatments. On the other hand, the lowest values of essential oil percentage were recorded in treatment 60% ETc and control (1.49 and 1.55%). While, the highest essential oil yield per plant (ml) or per feddan (L), were 4.05 and 4.09 ml/plant and 52.59 and 53.20 l/fed., by AA3 (300 ppm) under 100% ETc in the two seasons, respectively, followed by 80% ETc combined with AA3 (300 ppm), there were no significant differences between them. But the lowest values of oil yield were recorded 0.80 and 1.11 ml/plant and 10.46 and 14.39 l/fed., by 60% ETo and untreated plants (control) in the two seasons, respectively.

According to **Khorasaninejad *et al.* (2011),** water stress has decreased the total growth parameters, essential oil percentage and its yield. According to a different study, the application of ascorbic acid greatly increases the yield of essential oil. This is because photosynthesis and secondary metabolite production are positively correlated, meaning that ascorbic acid applied externally to plants can maintain photosynthesis. **(Narimani *et al.*, 2020).** The previous studies of **El-Gamal (2005)** using 300 ppm ascorbic acid as well as of **Khalil *et al.* (2010)** using 100, 150, and 200 ppm ascorbic acid reported that, in line with the current findings, these treatments significantly increased the percentage of volatile oil in basil herb.

Table (11). Effect of irrigation levels and organic acids rates on essential oil productivity of fennel during 2020/2021 and 2021/2022 Seasons

Essential oil percentage								
Organic acid (OA)	**First season**				**Second season**			
	Irrigation levels (I)				**Irrigation levels (I)**			
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	1.49	1.56	1.54	**1.53**	1.55	1.63	1.60	**1.59**
SA1	1.84	1.99	1.87	**1.90**	1.91	2.07	1.95	**1.98**
SA2	2.11	2.25	2.18	**2.18**	2.20	2.34	2.26	**2.27**
SA3	2.16	2.33	2.28	**2.26**	2.25	2.43	2.37	**2.35**
AA1	2.04	2.13	2.12	**2.10**	2.13	2.22	2.21	**2.19**
AA2	2.20	2.33	2.14	**2.22**	2.29	2.42	2.22	**2.31**
AA3	2.44	2.51	2.50	**2.48**	2.53	2.62	2.60	**2.58**
Mean	**2.04**	**2.16**	**2.09**		**2.12**	**2.25**	**2.17**	
LSD (0.05)	**I=0.03 OA= 0.02 I*OA= 0.04**				**I=0.04 OA= 0.02 I*OA=0.07**			
	Essential oil yield/plant (ml)							
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	0.80	0.97	1.16	**0.98**	1.11	1.22	1.38	**1.24**
SA1	1.62	2.03	2.13	**1.93**	1.73	2.05	2.32	**2.03**
SA2	1.90	2.56	2.77	**2.41**	2.22	2.69	3.00	**2.64**
SA3	2.14	2.86	2.98	**2.66**	2.36	3.01	3.24	**2.87**
AA1	1.89	2.51	2.74	**2.38**	2.05	2.69	3.08	**2.61**
AA2	2.18	3.09	3.17	**2.82**	2.30	3.21	3.29	**2.93**
AA3	2.62	3.82	4.05	**3.49**	2.82	3.69	4.09	**3.53**
Mean	**1.88**	**2.55**	**2.71**		**2.08**	**2.65**	**2.91**	
LSD (0.05)	**I= 0.13 OA= 0.21 I*OA= 0.52**				**I=0.21 OA= 0.18 I*OA=0.45**			
	Essential oil yield/fed. (L)							
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	10.46	12.61	15.06	**12.71**	14.39	15.90	17.96	**16.08**
SA1	21.09	26.38	27.72	**25.06**	22.47	26.59	30.18	**26.41**
SA2	24.74	33.25	35.96	**31.32**	28.83	34.92	38.93	**34.23**
SA3	27.76	37.24	38.76	**34.58**	30.76	39.21	42.07	**37.35**
AA1	24.60	32.69	35.57	**30.95**	26.68	35.09	40.01	**33.93**
AA2	28.37	40.17	41.26	**36.60**	29.91	41.69	42.76	**38.12**
AA3	34.04	49.65	52.59	**45.43**	36.66	48.03	53.20	**45.97**
Mean	**24.44**	**33.14**	**35.28**		**27.10**	**34.49**	**37.87**	
LSD (0.05)	**I=2.11 OA= 2.25 I*OA=6.70**				**I= 3.16 OA= 2.19 I*OA=5.38**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

3.10. GLC analysis of essential oil components

Data in Table (12) showed the GC fractionated components analysis of the volatile oil of fennel plants of the first season as affected by irrigation and organic acids. It was clear that limonene, fenchone and Anthole were the main components of fennel oil. Also, volatile oil contained α –Pinene (1.02% to 3.33%), β–Pinene (0.42% to 2.90%), Myrcene (2.22% to 3.33%), Limonene (2.24% to 3.79%), 1.8 cineole (1.29% to 3.55%) Fenchone (6.78% to 10.23%), Estragole (1.19% to 4.88%) and Anethole (72.93% to 78.21%). It was observed that Anethole content was increased with increasing the irrigation level from 60 to 100% ETc. While, Fenchone decreased with increasing the irrigation level from 60 to 100% of ETc.

Concerning the effect of SA and AA doses on the different essential oil components, it could be observed that the highest Anethole content in fennel was observed in those plants sprayed by 300 ppm ascorbic acid under both rates of irrigation 80% ETc with mean value (78.21%), followed by 300 ppm salicylic acid under irrigation level 100% ETc with mean value 78.04%. The opposite trend was observed, where AA (300 ppm) treatment decreased Fenchone content under all irrigation levels compared to untreated plants and SA.

The relationship between anethole and fenchone was discovered to be up/down; that is, therapies had a positive effect on anethole content and negative effects on fenchone content.

Table (12). Effect of irrigation levels and organic acids rates on main components of essential oil of fennel plant in 2020/2021 season according to GC analysis

Components								
Treatments	**α-Pinene**	**β-Pinene**	**Myrcene**	**Limonene**	**1.8 Cineole**	**Fenchone**	**Estragole**	**Anethole**
I1	3.33	2.74	2.83	2.53	1.29	10.23	4.12	72.93
I2	2.57	2.90	2.34	3.79	2.34	8.12	4.41	73.53
I3	2.78	1.93	2.42	3.21	2.62	7.57	4.88	74.59
I1 SA3	1.02	1.75	3.33	3.66	3.15	10.21	3.4	73.48
I2 SA3	1.84	1.11	2.86	3.79	3.08	9.58	2.61	75.13
I3 SA3	1.41	1.46	2.22	2.24	3.55	7.63	3.45	78.04
I1 AA3	2.29	0.42	2.74	3.12	3.48	7.27	3.12	77.56
I2 AA3	2.53	0.55	2.43	3.74	2.93	7.13	2.48	78.21
I3 AA3	2.56	2.44	2.68	3.59	3.12	6.78	1.19	77.64

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, SA3=Salicylic acid at rate 300 ppm, AA3= Ascorbic acid at rate 300 ppm.

3.11. Total phenolic content and Antioxidant activity

Data presented in Table (13) pointed out that total phenols (mg/g DW) antioxidant activity (%) of fennel affected significantly by irrigation levels treatments in the two successive seasons. The decrease in irrigation level conducted to a significant increasing in antioxidant activity. The lowest irrigation level (60% ETc) showed significant superiority in phenolic content and antioxidant activity of fruits comparing to the other two levels (80% and 100 % ETc). Increasing irrigation from 80% ETc to 100 % ETc level, decrease significantly the antioxidant activity.

The best total phenols (10.06 and 10.94 mg/g) and antioxidant activity values (66.13 and 73.39 %) were obtained by irrigation at 60 % ETc in the first and the second seasons, respectively. Whilst the least values of total phenols (7.84 and 8.52 mg/g) and the antioxidant activity (61.40 and 68.16%) were resulted from 100 % ETc in the same respective seasons.

Increasing total phenols and antioxidant activity under irrigation at 60% ETc may be attributed to that under water stress, plants have evolved a variety of antioxidant defense mechanisms to shield themselves from reactive oxygen species (ROS). These methods rely on a number of low molecular weight antioxidants, such as ascorbic acid and phenolic substances, in addition to antioxidant enzymes such as catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD). **(Yang *et al.*, 2007).**

There are significant differences between total phenols and antioxidant activity values as a result of different foliar application treatments. Foliar application of ascorbic acid and salicylic acid at 300 ppm in both seasons.

Foliar application of 300 ppm ascorbic acid resulted in the maximum total phenols (12.69 and 13.78 mg/g) and antioxidant activity (70.50 and 78.26%) in the both seasons. On the other hand, the lowest values of phenols (6.47 and 7.03 mg/g) and Antioxidant activity (57.78 and 64.12%) were resulted from the control.

Clearly, antioxidant activity of fennel seeds responded significantly to the interaction between irrigation levels and the foliar application treatments (Table,13) The highest values of total phenols (13.71 and 14.89 mg/g) and antioxidant activity (73.53 and 81.62%) in the first and the second seasons were produced from the interaction between 60 % ETc irrigation level and 300 ppm ascorbic acid foliar application. Whilst, the minimum values of antioxidant activity were received from plants irrigated at 100 % ETc and sprayed with tap water (control).

Furthermore, **Kähkönen *et al.* (2001)** showed that ascorbic acid and fruit phenolic content could function in concert. A strong correlation between total phenol concentration and antioxidant activity was also demonstrated by the results. According to recent research, fruit's total phenolic content can be largely responsible for its antioxidant effectiveness. **Rapisarda *et al,* (1999).**

Table (13). Effect of irrigation levels and organic acid rates on total phenols content (mg/g) and antioxidant activity % of Fennel Fruits during 2020/2021 and 2021/2022 Seasons

	Total phenols (mg/g DW)							
Organic acid (OA)	**First season**				**Second season**			
	Irrigation levels (I)				**Irrigation levels (I)**			
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	7.16	6.66	5.58	**6.47**	7.79	7.24	6.06	**7.03**
SA1	8.77	7.60	5.87	**7.41**	9.53	8.26	6.38	**8.06**
SA2	9.21	8.05	6.68	**7.98**	10.01	8.75	7.26	**8.67**
SA3	9.52	8.79	7.10	**8.47**	10.35	9.55	7.71	**9.20**
AA1	10.21	9.52	8.12	**9.28**	11.10	10.35	8.82	**10.09**
AA2	11.87	11.46	9.92	**11.08**	12.90	12.46	10.78	**12.05**
AA3	13.71	12.73	11.63	**12.69**	14.89	13.83	12.63	**13.78**
Mean	**10.06**	**9.26**	**7.84**		**10.94**	**10.06**	**8.52**	
LSD (0.05)	**I=0.45 OA=0.49 I*OA=0.92**				**I=0.51 OA=0.55 I*OA=0.98**			
OA	**Antioxidant activity %**							
	I1	**I2**	**I3**	**Mean**	**I1**	**I2**	**I3**	**Mean**
Control	59.30	58.59	55.44	**57.78**	65.79	65.04	61.53	**64.12**
SA1	62.41	59.25	56.29	**59.32**	69.25	65.78	62.46	**65.83**
SA2	63.61	60.10	58.79	**60.83**	70.60	66.71	65.28	**67.53**
SA3	66.34	62.78	61.99	**63.70**	73.62	69.70	68.80	**70.71**
AA1	67.56	64.47	63.69	**65.24**	74.97	71.56	70.69	**72.41**
AA2	70.17	68.51	66.01	**68.23**	77.89	76.05	73.27	**75.74**
AA3	73.53	70.35	67.61	**70.50**	81.62	78.09	75.06	**78.26**
Mean	**66.13**	**63.44**	**61.40**		**73.39**	**70.42**	**68.16**	
LSD (0.05)	**I=1.87 OA= 1.45 I*OA=3.11**				**I=2.29 OA= 1.54 I*OA=2.94**			

*I1=60% ETc, I2=80% ETc, I3= 100 ETc, Control=Tap water, SA1= Salicylic acid at rate 100 ppm, SA2=Salicylic acid at rate 200 ppm, SA3=Salicylic acid at rate 300 ppm, AA1= Ascorbic acid at rate 100 ppm, AA2= Ascorbic acid at rate 200 ppm and AA3= Ascorbic acid at rate 300 ppm.

4. Conclusion

It could be concluded that application of ascorbic and salicylic acid has positive enhanced on fennel plants grown under various levels of water stress. Thus, it would be recommended that using ascorbic acid at rate 300 ppm and 100% or 80% ETc resulted in maximum increase irrigation water productivity and fennel yield performance.

References

Adams, R.P. (2007). In "Identification of Essential Oil Components by Gas Chromatography/mass Spectroscopy". 4th Edition. Allured, Carol Stream, Illinois and USA.

Ahmed A.A., K.M. Aboelkassem and E.M.M. Elnenny (2021). Effect of sprinkler and drip irrigation systems on seed yield and quality of oil for some sunflower genotypes. International Journal of Agricultural Sciences, 3 (3): 96-107.

Ahmadi-Mirabad, A.; M. Lotfi and M.R. Roozban (2014). Growth, yield, yield components and water-use efficiency in irrigated cantaloupes under full and deficit irrigation. Electronic Journal of Biology, 10(3): 79-84.

Ali, A.F.; E.A. Hassan; E.H. Hamad and W.M.H. Abo-Quta (2017). Effect of Compost, Ascorbic Acid and Salicylic Acid Treatments on Growth, Yield and Oil Production of Fennel Plant. Assiut J. Agric. Sci., (48) (1-1): 139-154.

Alobaidy, M.G. (2017). Effect of Putrescine and 24 Epibrassinolide on Growth, Yield and Chemical Compositions of Cotton Plant Grown Under Drought Stress Conditions. Ph.D. Thesis, Faculty of Agriculture, Cairo University, Egypt, 303p.

ASTA (1985). Official analytical methods of the American Spice Trade Association. 68 p.

Athar, H-R, Khan A, Ashraf M. (2008). Exogenously applied ascorbic acid alleviates salt-induced oxidative stress in wheat. Environ. Exp. Bot., 63:224– 231.

Azooz, M. M. and Al-Fredan, M. A. (2009). The inductive role of vitamin C and its mode of application on growth, water status, antioxidant enzyme activities and protein patterns of *Vicia faba* L cv. Hassawi grown under seawater irrigation. Amer. J. Plant. Physiol., 4: 38-51.

Bahreininejad, B.; J. Razmjoo and M. Mirza (2013). Influence of water stress on morpho-physiological and phytochemical traits in *Thymus daenensis*. Int. J. Plant Prod., 7(1): 155–166.

Badran, F.S.; Attia, F.A. and Ayat, A.M. (2013). Effect of macro/micro fertilization treatment as well as, Salicylic and ascorbic acid on growth, fruit yield and essential oil of coriander. Plants grown in sandy soil. The first Assiut Inter. Conf. of Horticulture. 24-27th Feb., 2013.

Badran, F. S., Ahmad, E. T., El-Ghadban, E. A., Ayyat, A. M. (2016). Effect of compost /NPK and biofertilization treatments on vegetative growth, yield and herb of fennel plants. Scientific J. Flowers & Ornamental Plants, 4 (2), p.: 175-185.

Corell, M.; M.C. Garcia; J.I. Contreras; M.L. Segura and P. Cermeño (2012). Effect of water stress on *Salvia officinalis* L. bioproductivity and its bioelement concentrations. Communications in Soil Science and Plant Analysis, 43(1-2): 419–425.

El-Gabas, N.M.M. (2006). Physiological Studies on The Effect of Ascorbic Acid and Micronutrients on Sunflower Plants Grown Under Salinity Stress. M.Sc. Thesis (Botany), Fac. Sci., Al-Azhar Univ., 247p.

El-Gamal, S. M.A., (2005). Physiological response of Sweet Basil plants grown under stress conditions as affected by yeast, ascorbic acid and potassium. Minufiy J. Agric. Res., 30(1): 25-50.

El-Gamal, M. A. S., Serag El-Din, M. W. and Mokhtar, N. A. Y.O. (2021). Integrated Effects of Biochar and Potassium Silicate on Borage Plant Under Different Irrigation Regimes in Sandy Soil. Journal of Horticultural Science & Ornamental Plants, 13 (1): 60-76.

Farouk, S., Mosa, A. A., Taha, A. A., Ibrahim Heba, M. and EL-Gahmery, A. M. (2011). Protective effect of ascorbic acid and chitosan on radish (*Raphanus sativus* L. var. *sativus*) plants subjected to cadmium stress. J. Stress Physiol. Biochem. 7(2):99-116.

FAO (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper 29, Food and Agriculture Organization: Rome, Italy.

FAO, (1977). Guidelines for predicting crop water requirements. In Irrigation and Drainage Paper, 24. By Doorenbos, J., and Pruitt, W. O.Eds.; Food and Agricultural Organization: Rome, Italy.

Farooq, M.; A. Wahid and D.J. Lee (2009). Exogenously applied polyamines increase drought tolerance of rice by improving leaf water status, photosynthesis and membrane properties. Acta Physiologia Plantarum, 31(5): 937-945.

Gahory, A. M. O., Ayyat, A. M. and Soliman, T. M. A. (2022). Growth, yield and its component of Coriander (*Coriandrum sativum* L.) in response to the addition of compost, ascorbic acid and salicylic acid under Aswan governorate conditions, Egypt. J. of Plant Production, Mansoura Univ., 13 (12): 899 -905.

García-Caparrós, P., Romero, M.J., Llanderal, A., Cermeño, P., Lao, M.T., Segura, M.L., (2019). Effects of drought stress on biomass, essential oil content, nutritional parameters, and costs of production in six Lamiaceae species. Water, 11(3): 1-12.

Ghassemi-Golezani, K.; S. Ghassemi and I. Yaghoubian (2017). Improving oil and flavonoid contents of milk thistle under water stress by salicylic acid. Adv. Hort. Sci., 31(1): 19-23.

Hammad, S.A.A. (1991). Physiological Response of Snap Bean Plant to Water Supply. M.Sc. Thesis, Agric. Botany Department, Fac. Agric., Minufiya University, 150 p.

Hossein, A.F.; A.V. Sayed; D. Jahanfar; H.S. Amir and A.K. Mohammad (2009). Medicinal and aromatic plants farming under drought conditions. Journal of Horticulture and Forestry, 1(6): 1086-1092.

Hussein, M.M.; A.I. Rezk; A. B. El- Nasharty and H.M. Mehanna (2015). Nutritional and growth response of canola plants to salicylic acid under salt stress conditions. International Journal of ChemTech Research, 8(6): 574-581.

Jensen, M. E. (1983). Design and Operation of Farm Irrigation Systems. American Society Agricultural Engineering, St. Joseph, USA, pp: 827.

Kabir, K. A. R., Islam, M. A. and Haque, M. R. (2009). Effect of seed rate and irrigation level on the performance of wheat cv. Gourab J Bangladesh Agri Univ., 7(1): 47- 52.

Kähkönen, M. P., Hopia, A. I., Heinonen. M. (2001). Berry phenolics and their antioxidant activity. J. Agric. Food Chem., 49: 4076-4082.

Kalamian, S., Modares S. S. and Sepehri, A. (2006). Effect of water deficit of at vegetative and reproductive growth stages in leafy and commercial hybrids of maize. Agric. Res., 5:38-53.

Kang, W. Y.; Song, Y. L. and Zhang, L. (2011). Glucosidase inhibitory and antioxidant properties and antidiabetic activity of *Hypericum ascyron* L, Med. Chem. Res., 20: 809–816.

Kenawy, A.G. (2010). Response of *Ammi visnaga*, L. plants to some organic and bio-fertilization treatments. Ph.D. Thesis, Fac. of Agric., Minia Univ. 207p.

Khan, I.A., (2001). The growth and yield responses of mungbean to variable seeding densities and irrigation levels. Crop Husbandry, 16: 115-120.

Khandaker, L.; A.M. Akond and S. Oba (2011). Foliar application of salicylic acid improved the growth, yield and leaf's bioactive compounds in red amaranth (*Amaranthus tricolor* L.). Vegetable Crops Research Bulletin, 74(1): 77-86.

Khalil, Soha E., Nahed G. Abd El- Aziz and Bedour H. Abou Leila, (2010). Effect of water stress, ascorbic acid and spraying time on some morphological and biochemical composition of *Ocimum basilicum* plant. Journal of American Science., 6(12): 33-44

Kleinwachter, M., Paulsen, J., Bloem, E., Schnug, E., Selmar, D., (2015). Moderate drought and signal transducer induced biosynthesis of relevant secondary metabolites in thyme (*Thymus vulgaris*), greatercelandine (*Chelidonium majus*) and parsley (*Petroselinum crispum*). Ind. Crops. Prod., 64: 158–166.

Khorasaninejad, S., Mousavi, A., Soltanloo, H., Hemmati, K. and Khalighi, A., (2011). The effect of drought stress on growth parameters, essential oil yield and constituent of Peppermint (*Mentha piperita* L.). Journal of Medicinal Plants Research, vol. 5, no. 22, pp. 5360-5365.

Mehanna, M.H.; H.A. Said-Al Ahl; M.H. Mohamed; N. Wonder and N.M. Fhatuwani (2015). Yield and essential oil response in coriander to water stress and phosphorus fertilizer application. Journal of Essential Oil Bearing Plants, 18(1): 82-92.

Mehta, R. S., Anwer, M. M. and Aishwath, O. P. (2011). Growth and yield of fennel (*Foeniculum vulgare* Mill.) as influenced by irrigation, nutrient levels and crop geometry. Journal of Spices and Aromatic Crops, 20 (2): 77–80.

Mohamed, M. Kh., Ali, A. F. and Ibrahim, M. F. (2022). Fennel (*Foeniculum Vulgare* Mill.) growth, productivity and essential oil yield under different sowing methods and some stimulant substances. Archives of Agriculture sciences journal. 5(3): 41-61.

Narimani, R., Moghaddam, M. and Pirbalouti, P.G. (2020). Phytochemical changes of *Dracocephalum moldavica* L. Essential oil under different salinity stresses and application of humic and ascorbic acid. Eco phytochemical Ecophytochemical Journal of Medicinal Plants, vol. 7, no. 4, pp. 34-48.

Nadjafi, F. (2006). Evaluation the ecological criteria of *Nepeta binaludensis* Jamzad for adaptation in low input agricultural systems. PhD Thesis of Agroecology. Ferdowsi University of Mashhad, Iran.120 pp.

Rapisarda, P., Tomaino, A., Cascio, R. L., Bonina, F., De Pasquale, A., Saija. A. (1999). Antioxidant effectiveness as influenced by phenolic content of fresh orange juices. J. Agric. Food Chem., 47, 4718-4723.

Rioba, N.B., Itulya, F.M., Saidi, M., Dudai, N., Bernstein, N., (2015). Effects of nitrogen, phosphorus and irrigation frequency on essential oil content and composition of sage (*Salvia officinalis* L.). J. Appl. Res. Med. Aromat. Plants. 2 (1), 21–29.

Saeidi-Sar, S., Abbaspour, H., Afshari, H. and Yaghoobi, S. R. (2013). Effects of ascorbic acid and gibberellin A3 on alleviation of salt stress in common bean (*Phaseolus vulgaris* L.) seedlings. Acta. Physiol. Plant, 35: 667–677.

Saha, A.; Chakraborty, L. and Das, K. (2020). Effect of foliar application of acetyl salicylic acid, ascorbic acid and riboflavin on growth, yield and yield component of French bean

(*Phaseolus vulgaris* L. Cv. Arka Arjun). International Journal of Chemical Studies, 8(2): 1802-1806.

Serag El-Din, M. W. and Mokhtar, N. A. Y.O. (2020). Effect of Irrigation Scheduling and some Antitranspirants on Water Relations and Productivity of *Mentha varidis* L. American-Eurasian J. Agric. & Environ. Sci., 20 (5): 367-390.

Shil, S. and Dewanjee, S. (2022). Impact of drought stress signals on growth and secondary metabolites (SMs) in medicinal plants. The Journal of Phytopharmacology, 11(5):371-376.

Singh, M. and Ramesh, S. (2000). Effect of irrigation and nitrogen on herbage, oil yield and water-use efficiency in rosemary grown under semi-arid tropical conditions. J. Med. Aromat. Plant Sci., 22 (1B): 659-662.

Steel, R. G. D. and Torrie, J. H. (1980). Principles and procedures of statistics. A biometrical approach, 2nd Edition, McGraw-Hill Book Company, New York.

Tupe, R. S.; Kemse, N. G. and Khaire, A. A. (2013). Evaluation of antioxidant potentials and total phenolic contents of selected Indian herbs powder extracts. International Food Research Journal, 20:1053-1063.

Vermeiren, L. and Jopling, G. A. (1984). Localized irrigation: Design, installation, operation, evaluation. In FAO Irrigation and Drainage Paper, 36 Food and Agricultural Organization: Rome, Italy.

Yang, D.M.; Q.S. Wang; L.Q. Ke; J.M. Jiang and T.J. Ying (2007). Antioxidant activities of various extracts of lotus (*Nelumbo nuficera* Gaertn) rhizome. Asia Pacific Journal of Clinical Nutrition, 16(1): 158-163.

Yancy, P. H., Clark, M. E., Hand, S. C., Bowlus, R. D. and Somero, G. N. (1982). Living with water stress: evolution of osmolyte systems, Science, 217: 1214–1223.

Wang, X., Ming-rong, H. E., Li, F., Younghuan, L. I. U., Hong-hua, Z. and Chungang, L. I. U. (2010). Coupling effects of irrigation and nitrogen fertilizer on grain protein and starch quality of strong-gluten winter wheat. Front. Agric. China., 2: (3), 274-280.

Zehtab-Salmasi, S., Javanshir, A., Omidbaigi, R., Aly-Ari and Gheassemi Golezani, K. (2001). Effects of water supply and sowing date on performance and essential oil production of anise (*Pimpinella anisum* L.). Acta Agron. Hung., 49 (1): 75-81.

Zhang, Y. (2013). Ascorbic acid in plants: biosynthesis, regulation and enhancement. Springer Briefs in Plant Science. New York: Springer.