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Comparative Study on the Effect of Pre-Sowing Seed Treatments and Ethrel Foliar Application on Growth, Fruiting and Essential Oil Content of *Foeniculum vulgare* Mill. Plants

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ABSTRACT

In pot experiments, the effects of pre-sowing seed treatments [cooling (2°C/24 h), heating (40°C/30 min) or soaking in 100 mg/1 gibberellic acid alone or in combination with a foliar application of ethrel at several concentrations (0, 250, 500 or 1000 mg/1)] on fennel (*Foeniculum vulgare* Mill.) plants were assessed. There was a significant increase in the majority of growth parameters (plant height, number of branches/plant, fresh and dry weight of shoot, and shoot/root ratio) as a result of pre-sowing seeds, especially soaking and heat treatments. When plants were cooled, then heated, then soaked they contained more leaf pigments (chlorophyll *a* and *b*, total chlorophylls and total carotenoids) and total carbohydrate accompanied by a parallel acceleration in flowering and ripening dates. Hardening of fennel through the application of heat resulted in the greatest plant fruit yield and the highest essential oil (EO) yield in both milky and harvest stages. Spraying ethrel at a low concentration (250 mg/1) enhanced growth parameters, leaf pigments and total carbohydrate in most cases; an opposite effect was noticed under the highest concentration used (1000 mg/1), even though all ethrel concentrations accelerated flowering and ripening dates. The highest EO yield was with 500 mg/l ethrel during milky and harvest stages. There was a synergistic effect between pre-sowing seed treatments and the use of low and moderate levels of ethrel in most cases; the combined effect between soaking treatments and ethrel at 250 mg/1 resulted in the highest values of most growth parameters during the milky stage while the combined (cooling treatment + 250 mg/1 ethrel) treatment resulted in more leaf pigments, total carbohydrate and accelerated flowering and ripening dates. The combination between heat hardening + 500 mg/l ethrel resulted in the highest EO yield during milky and harvest stages. These results demonstrate that heating fennel seeds at 40°C for half an hour could be used effectively for increasing the fruit and EO yield of plants. This increment can be improved by ethrel foliar spray at 50 mg/l.

Keywords: acceleration, cooling, growth retardant, heating, soaking
Abbreviations: dw, dry weight; **EO**, essential oil; **fw**, fresh weight; **GA_3**, gibberellic acid; **Fd**, flowering date; **Rd**, ripe date

INTRODUCTION

Medicinal and aromatic plants (MAPs) are one of the most important sources for increasing the economy through agriculture of many countries and may prove to be useful as small-scale industrial or arable crops for Egyptian farmers, particularly in newly reclaimed soils (Khalil *et al.* 2001). Fennel (*Foeniculum vulgare* Mill.) is an annual plant that belongs to the Apiaceae family and is cultivated for its fruits, which are frequently used for medical and culinary purposes. The medical properties of these fruits depend upon their essential oil (EO), which is warm, pungent and aromatic. A few drops of its oil or half a teaspoonful of the seeds are good remedies for colic and gastrodynia. Also, fennel seeds are frequently added to bread and biscuits for flavor and for aiding digestion (Graves 1990). Fennel seed oil has been shown to reduce intestinal spasms and increase motility of the small intestine, thus reducing infantile colic with no side effects (Alexanderovich *et al.* 2003).

The influence of temperature is very important, not for normal plant development but also for continuation of many physiochemical processes (Levitt 1972). Temperature is one of the decisive environmental factors which determines development and controls plant metabolic pathways (Reda *et al.* 1977). The simulative effect of pre-sowing seed (heat or cold) on growth, yield production and active ingredients of some MAPs and other crop plants was reported by many Egyptian investigators (Reda and Hegazy 1973; Reda and Ashour 1974; Reda *et al.* 1977; Khalil and Reda 1980; El-Moursi *et al.* 1986; Reda *et al.* 1985). In addition, the connection between heat shock and common stress tolerance were studied by Panchuk *et al*. (2002).

Since gibberellic acid (GA_3) is not harmful to human health, it can be applied for different purposes (Korkutal *et al.* 2008). Gibberellins control many aspects of plant growth and development: seed germination, leaf expansion, stem elongation, flowering and flower development (Yamaguchi and Kamiya 2002). The ethylene content of plants is correlated with their sex expression; in this regard, application of ethylene decreased the number of male flowers and increased the number of bisexual flowers of coriander plants (Amruthavalli 1978; Helal 1987).

The aim of this work was to compare the effects of pre-sowing seed treatments (heating, cooling and soaking in GA_3) as well as ethrel foliar application and their combinations for improving the growth, fruiting and EO content of fennel plants.

MATERIALS AND METHODS

Pot experiments were conducted over two successive seasons (2005/2006 and 2006/2007) in greenhouses of the Botany Department, National Research Centre (NRC), Egypt. Fennel seed (*Foeniculum vulgare* Mill var. 'Balady') were supplied from the Genetics and Cytology Department, NRC. Fennel seed were sown in seed beds (using five beds, each bed 35 × 35 cm, 3.5 cm between seeds, 100 seeds per bed) on the 15th October in both seasons after the three following pre-sowing treatments: cooled at 2°C/24 h;

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heated at 40°C/30 min; soaked for 24 h in a freshly prepared solution of GA_3 (obtained commercially as Berelex tablets from Imperial Chemical Industries Ltd., England) at 100 mg/l; untreated plants (control). 45-day-old seedlings were individually transplanted in plastic pots (12,672 cm^3) filled with about 10 kg loam: sand: silt (1: 1: 1, v/v) mixed with 4 g calcium superphosphate (15.5% P_2O_5). Nitrogen and potassium fertilizers were added in two batches, 3 and 5 weeks from transplanting at the rate of 4 g/pot in the form of ammonium sulphate (20.6% N) and 2 g/pot in the form of potassium sulphate (48% K_2O). In the greenhouse, the plants from each pre-sowing treatment were sprayed twice with ethrel (supplied by A Rancher-Amchum Company, USA) at 0, 250, 500 or 1000 mg/l at 30 and 45 days from transplanting using a hand-held sprayer (on average 20 ml/plant) to completely cover the plant foliage. The experiment included 16 treatments, which consisted of four pre-sowing seed treatments in combination with the four ethrel concentrations. These were arranged in a completely randomized design with 3 replicates, each replicate containing 9 pots. The photosynthetic pigments (chlorophyll (Chl) *a*, *b*, total Chls and total carotenoids) in fresh leaf samples were determined according to Saric *et al.* (1971) two weeks after the last spray. In addition, total carbohydrate content in dried leaves was determined according to Herbert *et al.* (1971). The days until the appearance of the main umbel flowered after treatment (flowering date) and days to ripening of main umbel fruits (ripe fruiting date) were recorded. In both seasons, two samples were taken for the following characters at the milky stage (160 days from sowing): plant height, number of branches/plant, fresh (fw) and dry (dw) shoot and root weights as well as shoot/root ratio, stalk length of the main umbel, number of umbellets/main umbel, main umbel fruit weight, weight of 100-fruits, plant fruit yield as well as EO percentage and yield in the first sample. The second sample was taken during harvest (210 days-old) according to Guenther (1961). Combined analysis for data of the two seasons and L.S.D. values were calculated according to Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Growth characters

Data presented in **Table 1A** and **Fig. 1** show the changes in growth characters of fennel plants as affected by per-sowing seeds treatments.

There was a significant increase in plant height, shoot fw as well as shoot/root dw ratio in the cooled treatment. Similarly, Reda *et al.* (1977) found that exposure of *Ammi visnaga* L. to 3°C resulted in the most pronounced increases in the dw of different plant organs. In addition, El-Moursi *et al.* (1985) reported that hardening peppermint (*Mentha piperita* L.) plants with low temperature, particularly at 4°C for 12 days before transplanting improved plant growth. A pronounced increment was shown in growth characters of heated fennel plants in most cases, especially the number of branches, dw of roots and shoot/root fw. Pre-sowing heat treatments had a positive effect on *Zea mays* L. vegetative growth, especially with 40°C treatment (Reda and Saleh 1972). A significant increase of maize stem and internodes length explained the increase in the height of plants resulting from pre-sowing treatments. In addition, the increase of fresh weight of plants was attributed to increased water content (Reda and Hegazy 1973). Also, Reda *et al.* (1977) suggested that per-sowing heat treatment stimulated the physiological processes at a higher level within the cells of heat-hardened *Ammi visnaga* plants. The highest increments in plant height, fw and dw of shoots, fw of roots and shoot/root ratio (dw) were recorded by soaking the seeds in GA_3

Table 1A Effect of pre-sowing seeds and ethrel treatments on growth characters of fennel plant milky stage.

Growth characters								Treatments	
Shrr		Rw		Shw		Bn	Ph		
Dw	Fw	Dw	Fw	Dw	Fw				
1.91	2.18	5.65	20.07	10.64	42.86	6.13	65.99	Control	Pre-sowing seeds
2.19	2.31	5.19	19.06	11.32	43.88	6.24	73.39	Cooling	
2.17	2.49	5.83	19.29	12.63	47.91	6.82	70.86	Heating	
2.22	2.42	5.75	19.90	12.74	48.12	6.72	74.27	Soaking	
0.05	0.05	0.09	0.33	0.14	0.61	0.15	0.34	LSD 5%	
2.16	2.31	5.48	20.03	11.81	46.10	5.54	74.00	Control	Ethrel concentration
2.04	2.22	6.68	23.16	13.55	51.27	7.51	80.27	250	(mg/l)
2.20	2.47	5.34	18.92	11.72	46.61	6.96	69.62	500	
2.09	2.40	4.92	16.21	10.25	38.79	5.90	60.56	1000	
0.06	0.08	0.12	0.45	0.17	0.71	0.16	0.68	LSD 5%	

Values indicate the means of two seasons.
Ph = plant height, Bn = branch number/plant, Shw = shoot weight (g/plant), Rw = root weight (g/plant), Shrr = shoot/root ratio, Fw = fresh weight, Dw = dry weight

Table 1B The combined effect of pre-sowing seeds and ethrel treatments on growth characters of fennel plant during milky stage.

Combined treatments				Growth characters					
Pre-sowing	Ethrel conc.	Ph	Bn	Shw		Rw		Shrr	
treatment	(mg/l)			Dw	Fw	Dw	Fw	Dw	Fw
Control	0	60.78	4.25	36.46	8.90	21.00	5.52	1.74	1.61
	250	75.28	7.28	47.38	12.78	24.00	7.19	1.97	1.78
	500	70.67	6.98	45.66	10.65	19.51	5.30	2.35	2.01
	1000	57.22	6.01	41.91	10.24	15.79	4.60	5.65	2.23
Cooling	0	78.50	5.68	45.38	11.09	17.90	4.79	2.54	2.32
	250	81.17	7.02	48.83	12.46	22.89	5.91	2.13	2.11
	500	73.17	6.32	44.94	11.62	18.42	4.96	2.44	2.34
	1000	60.72	5.92	36.38	10.12	17.02	5.09	2.14	1.99
Heating	0	73.90	6.95	50.94	12.87	20.42	5.96	2.50	2.16
	250	78.50	7.61	54.06	14.27	22.04	6.54	2.45	2.18
	500	68.33	7.10	45.74	12.37	18.89	5.86	2.42	2.11
	1000	62.70	5.62	40.91	11.02	15.81	4.95	2.59	2.17
Soaking	0	83.17	5.28	51.61	14.40	20.80	5.66	2.48	2.54
	250	86.00	8.12	54.79	14.70	23.71	7.10	2.31	2.07
	500	66.32	7.43	50.11	12.25	18.88	5.24	2.65	2.34
	1000	61.61	6.05	35.97	9.61	16.22	4.98	2.22	1.93
LSD 5%		1.37	0.32	1.92	0.34	0.89	0.25	0.15	0.12

Values indicate the means of two seasons.
Ph = plant height, Bn = branch number/plant, Shw = shoot weight (g/plant), Rw = root weight (g/plant), Shrr = shoot/root ratio, Fw = fresh weight, Dw = dry weight

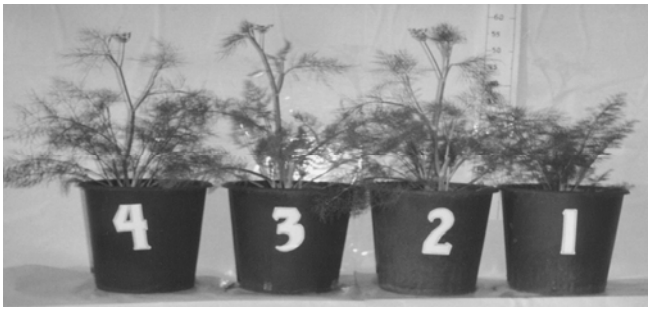

Fig. 1 Effect of pre-sowing treatments on the growth and flowering of fennel plant. Treatments: 1, control; 2, cooling (2°C/24 h); 3, soaking (100 mg/l GA_3/24 h); 4, heating (40°C/30 min).

Fig. 2 Effect of ethrel concentration on growth and flowering of fennel plant. Treatments: 1, Control; 5, ethrel (250 mg/l); 6, ethrel (500 mg/l); 7, ethrel (1000 mg/l).

Fig. 3 Effect of pre-sowing (cooling) on the growth and flowering of fennel plant under ethrel concentration. Treatments: 1, control; 2, cooling; 8, cooling + 250 mg/l ethrel; 11, cooling + 500 mg/l ethrel; 14, cooling + 1000 mg/l ethrel.

Fig. 4 Effect of pre-sowing (soaking) on the growth and flowering of fennel plant under ethrel concentration. Treatments: 1, control; 3, soaking; 9, soaking + 250 mg/l ethrel; 12, soaking + 500 mg/l ethrel; 15, soaking + 1000 mg/l ethrel.

Fig. 5 Effect of pre-sowing (heating) on the growth and flowering of fennel plant under ethrel. Treatments: 1, control; 4, heating; 10, heating +250 mg/l ethrel; 13, heatling + 500 mg/l ethrel; 16, heating + 1000 mg/l ethrel.

solution. Eid and Abou-Leila (2006) showed that the tallest croton (*Codiameum variegatum* L.cv. 'Norma') plants with the largest leaf area, the highest relative growth rate as well as fw and dw/plant were associated with GA_3 (50, 100 and 150 mg/l) treatments. Enhanced vegetative growth characteristics due to the application of GA_3 was reported by many groups working with different plants, including the Apiaceae: Ahmed and Eid (1982) on fennel (*Foeniculuml vulgare* Mill.), caraway (*Carum carvi* L.) and anise (*Pimpinella anisum*); Haikal and Badr (1982) on caraway (*Coriandrum sativum* L.); Ahmed (1990) and El-Keltawi *et al.* (2000) on cumin (*Cuminum cyminum*). Also related to this, Hegazy *et al.* (1990) reported that soaking cowpea (*Vigna sinensis* var. 'Fetriat') seeds in GA_3 solution (40 ppm) increased the amount of growth promoters (indole-3-acetic acid and indole acetonitrile) and decreased the amount of growth inhibitors (abscisic acid). Bialecka and Kepczynski (2003) found that exogenous GA_3 controlled both α-amylase activity and seed germination of *Amaranthus caudatus* plants.

Concerning the effect of ethrel, data presented in **Table 1A** and **Fig. 2** show that significantly higher mean values of plant height, number of branches/plant, fw and dw of both shoots and roots were observed with a lower concentration of ethrel (250 mg/l), whereas growth characters fluctuated between a slight decrease or an increase under a moderate concentration (500 mg/l) of ethrel; on the other hand, a higher concentration (1000 mg/l) resulted in lower values of all growth characters. The same trend in increasing vegetative growth characters as affected by the lower concentration of ethrel (250 mg/l) while the higher (1000 mg/l) inhibited it was obtained by Kamel *et al.* (1988) on basil (*Ocimum basilicum* L.) and Amin *et al.* (2008) on onion (*Allium cepa* L.) plants.

Considering the combined effect, data presented in **Table 1B** and **Figs. 2-5** reveal that, in relation to untreated plants, there was a significant increase in plant height, number of branches/plant, fw and dw of shoots as well as shoot/root ratio in per-sowing treated plants under both the lower and moderate concentration of ethrel (250 and 500 mg/l) in most cases. Moreover, there was a synergistic effect between all used per-sowing treatments and ethrel concentration at 250 mg/l in comparison with per-sowing seed alone or untreated plants. The combination between soaking treatment and ethrel at 250 mg/l recorded the highest value in most cases.

Photosynthetic pigments and total carbohydrate

Photosynthetic pigments content (Chl *a* and *b*, total Chls (*a* + *b*), total carotenoids), total carbohydrate, flowering date and ripe fruiting date as effected by per-sowing seed treatments (cooling, heating and soaking in GA_3) are presented in **Table 2A**. The data indicate that per-sowing seed plants showed a significant increase in leaf pigments and carbohydrate content accompanied with acceleration in both the flowering and ripe fruiting dates while cooling treatment recorded the highest values in comparison with other pre-sowing seed or untreated plants except for the higher carbohydrate content, which resulted from heating plants. Reda and Ashour (1974) showed that pre-sowing sugar beet (*Beta vulgaris* L.) fruits in cold (0 and 10°C) temperature treatments and heat (40 and 50°C) resulted in marked increases in the fw and dw of all plant organs; in addition, cold treatments were more effective than heat treatments, and the

increase in leaf dw due to different temperature treatments was mainly attributed to the pronounced increase in the number of green leaves produced by the treated plants as well as their area, while an increase in the photosynthetic activity of treated plants might have led to an increase in the productivity of the photosynthetic apparatus; such increases in plant growth seemed to be due, at least partially, to the changes in the physio-chemical properties of the protoplasm. According to Guo *et al.* (2004) vernalization is an important factor for cauliflower (*Brassica deracea* var. *botrytis*) flowering; in addition, days to flower bud appearance and anthesis were reduced in GA_3 (100 mg/l) treatments, so endogenous GAs might have some role in bolting and the flowering processes of cauliflower. Reda and Baker (1972) reported that *Atropa belladonna* L. treated with GA_3 (100 mg/l) significantly enhanced both the processes of flowering and of fruiting compared with the controls, and plants treated with 100 mg/1 GA_3 yielded flowers 14 days earlier and fruits 12 days earlier than the controls. Spraying of 50 ppm GA_3 on gladiolus (*Gladiolus grandiflorus*) plants (45 days old) significantly shortened the vegetative growth period and enhanced gladiolus flowering compared to untreated plants (Awad *et al.* 1982). There is additional evidence that GAs with more florigenic structures can induce flowering (King and Evans 2003), which explain the acceleration in flowering and fruiting dates as affected by GA_3 soaking.

Concerning the effect of ethrel, the same data in **Table 2A** and **Fig. 2** shows that there were significant increases in leaf pigments (Chl *a* and *b*, total Chls (*a* + *b*), total carotenoids) as well as total carbohydrate with the lower and moderate concentration of ethrel (250 and 500 mg/1), the latter being superior, recording the highest values, whereas the minimum value was obtained by the higher concentration of ethrel (1000 mg/1). Khan *et al.* (2003) found that spraying mustard plants with ethrel at 200 ppm enhanced the leaf photosynthetic rate. All used ethrel doses resulted in both accelerated flowering and ripe fruiting dates, the lower and moderate concentration being more effective than the higher one.

Considering the combined effect, except for the combination between soaked seeds in GA_3 and the higher concentration of ethrel (1000 mg/1), all used combinations between pre-sowing seed treatments and ethrel concentrations resulted in a significant increase in leaf pigments (Chl *a* and *b*, total Chls (*a* + *b*), total carotenoids) as well as total carbohydrate compared with untreated plants, as shown in **Table 2B**. The combinations between pre-sowing seeds (cooling, heating and soaking) and the lower concentration of ethrel were more effective than other combinations with moderate and higher concentrations of ethrel, i.e. the superior combination was between cooled plants and ethrel at 250 mg/1. All combinations used reduced the time to flowering and fruit ripening. This primitive effect on leaf pigments, total carbohydrate and shorting flowering and ripening dates could be attributed to the synergistic effect between pre-sowing seed treatments and ethrel concentrations, especially the lower one.

Yield characters during milky stage

Data presented in **Table 3A** indicates that pre-sowing seeds (cooling, heating and soaking) markedly favored the yield

Table 2A Effect of pre-sowing seeds and ethrel treatments on leaf pigments, carbohydrate percentage, flowering and ripe fruiting dates of fennel plant.

Rd	Fd	T carb. (%)	Leaf pigments				Treatments	
			T car.	Tch	Chl *b*	Chl *a*		
190.25	117.08	34.00	0.49	0.88	0.28	0.60	Control	Pre-sowing seeds
181.92	106.92	39.47	0.62	1.17	0.36	0.81	Cooling	
185.00	112.75	39.79	0.60	1.16	0.35	0.80	Heating	
185.00	112.75	35.40	0.56	1.02	0.33	0.69	Soaking	
0.80	0.79	0.25	0.02	0.06	0.03	0.05	LSD 5%	
189.67	116.67	36.05	0.54	1.00	0.32	0.68	Control	Ethrel concentration
183.42	109.50	40.24	0.64	1.26	0.38	0.88	250	(mg/l)
183.75	109.75	37.94	0.57	1.04	0.33	0.71	500	
185.33	113.58	34.43	0.52	0.92	0.29	0.63	1000	
1.94	1.32	0.28	0.02	0.04	0.02	0.03	LSD 5%	

Values indicate the means of two seasons.
Chl *a* = Chlorophyll *a*, Chl *b* = Chlorophyll *b*, Tch = total chlorophylls (*a*+*b*), T car. = total carotenoids, T carb. = total carbohydrates (%), Fd = flowering date, Rd = ripe fruiting date

Table 2B The combined effect of pre-sowing seeds and ethrel treatments on leaf pigments, carbohydrate percentage, flowering and ripe fruiting dates of fennel plant.

Combined treatments		Leaf pigments				T carb. (%)	Fd	Rd
Pre-sowing treatment	Ethrel conc. (mg/l)	Chl *a*	Chl *b*	Tch	T car.			
Control	0	0.57	0.27	0.84	0.48	32.11	126.00	203.00
	250	0.74	0.32	1.06	0.55	37.75	112.00	188.00
	500	0.57	0.26	0.83	0.48	35.22	114.00	186.00
	1000	0.51	0.25	0.76	0.43	30.29	116.00	184.00
Cooling	0	0.66	0.31	0.97	0.55	36.35	111.00	182.00
	250	1.01	0.44	1.45	0.71	43.01	102.00	180.00
	500	0.82	0.35	1.16	0.63	40.54	106.00	180.33
	1000	0.77	0.34	1.10	0.61	37.99	108.00	185.33
Heating	0	0.81	0.37	1.19	0.60	40.98	116.00	183.33
	250	0.96	0.38	1.35	0.67	42.01	111.00	182.00
	500	0.73	0.34	1.07	0.57	39.22	108.00	183.67
	1000	0.70	0.32	1.02	0.55	36.05	116.00	189.00
Soaking	0	0.68	0.31	1.00	0.53	34.77	114.00	188.33
	250	0.82	0.37	1.19	0.61	38.18	112.00	183.67
	500	0.74	0.37	1.10	0.61	36.77	111.00	185.00
	1000	0.54	0.26	0.78	0.49	31.88	114.00	183.00
LSD 5%		0.07	0.05	0.08	0.04	0.57	2.64	3.89

Values indicate the means of two seasons.
Chl *a* = Chlorophyll *a*, Chl *b* = Chlorophyll *b*, Tch = total chlorophylls (*a*+*b*), T car. = total carotenoids, T carb. = total carbohydrates (%), Fd = flowering date, Rd = ripe fruiting date

Table 3A Effect of pre-sowing seeds and ethrel treatments on yield characters, essential oil percentage and yield of fennel plants during the milky stage.

Yield characters (milky stage)							Treatments	
EOy	**EO (%)**	**Pfy**	**100 Fw**	**Mufw**	**Nu**	**Sl**		
0.239	0.72	44.78	3.55	11.38	18.34	9.85	Control	Pre-sowings seeds
0.373	0.83	44.79	3.16	11.60	20.42	10.45	Cooling	
0.408	0.77	52.84	4.15	11.76	18.13	10.81	Heating	
0.323	0.63	51.25	3.50	13.32	22.42	10.81	Soaking	
0.005	0.01	0.33	N.S	0.25	0.41	0.25	LSD5%	
0.326	0.73	45.24	3.16	11.35	19.06	10.48	Control	Ethrel concentration
0.348	0.73	46.79	3.69	12.29	20.83	11.93	250	(mg/l)
0.414	0.78	53.41	3.79	12.25	20.52	10.67	500	
0.346	0.72	48.23	3.54	12.17	18.95	8.83	1000	
0.005	0.01	0.40	N.S	0.28	0.34	0.25	LSD5%	

Values indicate the means of two seasons.
Sl = stalk length of main umbel (cm), Nu = number of umbellets/main umbel, Mufw = main umbel fruit weight (g/plant), 100 fw = fresh weight of 100 fruits (g/plant), Pfy = plant fruit yield (g/plant), EO % = relative percentage essential oil (w/v), EOy = essential oil yield (ml)

Table 3B The combined effect of pre-sowing seeds and ethrel treatments on yield characters, essential oil percentage and yield of fennel plant during milky stage.

Combined treatments		Yield characters (milky stage)						
Per-sowing treatment	**Ethrel conc. (mg/l)**	**Sl**	**Nu**	**Mufw**	**100 Fw**	**Pfy**	**Eo (%)**	**Eoy**
Control	0	9.05	16.75	8.93	2.63	37.60	0.63	0.238
	250	11.64	20.02	12.83	3.90	42.15	0.60	0.251
	500	10.78	20.58	13.21	3.86	50.30	0.86	0.432
	1000	7.92	16.03	10.54	3.80	49.08	0.80	0.393
Cooling	0	12.00	19.50	12.67	3.00	45.94	0.85	0.391
	250	11.40	20.48	8.79	3.61	39.16	0.91	0.355
	500	10.64	18.80	10.81	3.39	53.60	0.84	0.450
	1000	7.75	22.88	14.10	2.63	40.48	0.73	0.295
Heating	0	11.41	17.47	11.33	3.83	55.55	0.70	0.388
	250	11.75	20.03	12.55	5.29	50.18	0.79	0.396
	500	10.58	19.70	12.48	3.43	56.76	0.82	0.465
	1000	9.48	15.30	10.68	4.06	48.87	0.79	0.386
Soaking	0	9.45	22.50	12.46	3.18	46.87	0.67	0.314
	250	12.93	22.79	14.97	3.07	50.79	0.58	0.297
	500	10.68	23.01	12.50	4.09	54.17	0.71	0.385
	1000	10.17	21.38	13.34	3.68	53.17	0.56	0.298
LSD 5%		0.50	0.67	0.56	N. S	0.80	0.02	0.010

Values indicate the means of two seasons.
Sl = stalk length of main umbel (cm), Nu = number of umbellets/main umbel, Mufw = main umbel fruit weight (g/plant), 100 fw = fresh weight of 100 fruits (g/plant), Pfy = plant fruit yield (g/plant), EO % = relative percentage essential oil (w/v), EOy = essential oil yield (ml)

characters of fennel plants. Stalk length of the main umbel, number of umbellets/main umbel, and main umbel fruit weight increased significantly as a result of pre-sowing seed treatments. Even though soaked seeds recorded the highest stalk length of the main umbel, number of umbellets/main umbel and fruit weight values, the lowest EO percentage yield was recorded. The highest weight of 100-fruits, plant fruit yield and EO yield values were recorded by heat-hardened plants while the highest EO percentage resulted from cold-treated plants. The ability to increased EO yield of heated-treated and cooled fennel plants over soaked and untreated plants was related with their higher levels of leaf pigments and carbohydrate accumulation. Reda *et al.* (1985) found that peppermint (*Mentha piperita* L.) plants heated at 40 or 60°C enhanced plant growth and significantly favourable increases in EO production. In contrast, an increase in EO yield of peppermint plants as a result of exposing plants to low temperature (4°C) plants was recorded by El-Moursi *et al.* (1986). This pronounced effect of heat hardening on EO content and yield in the former study might be attributed to the high amount of intermediate products of metabolic pool which participated in the biosynthesis of EO and/or the activation of responsible specific enzymes involved in their biosynthesis. Also, Behairy and El-Habbasha (1979) reported that heat treatment was associated with increase in the occurrence of certain free amino acids in leaves and stems of squash (*Cucurbita pepo* L.) plants during growth, high number of female flowers, higher ratio of female to male flower accompanied by increase in total yield in plants grown from pre-sowing seed treatment with 40 and 60°C. They added that the effect of cold hardening on EO yield could be attributed to its effect on plant metabolism. Concerning the effect of GA_3, Arafa (1982) found that spraying fennel plants with GA_3 at 75, 150 or 300 mg/l decreased the weight of 1000-seeds. In caraway (*Carium carvi* L.) plants Sarhan and El-Sayed (1983) reported that GA_3 at 100 ppm slightly increased the number of setting and total umbels per plant. Also, El-Moursi (1980) showed an increase in the weight of seeds as a result of GA_3 treatments in *Ammi visnaga* L. plants. According to Ahmed and Eid (1975) on some umbelliferous plants and Mohamed *et al.* (1983) on *Pelargonium graveolens* GA_3 treatment resulted in a decrease in both EO percentage and yield.

Considering the effect of ethrel, a moderate concentration of ethrel (500 mg/l) resulted in higher values of plant fruit yield, EO percentage and yield although it ranked second order after the lower concentration (250 mg/l) in increasing stalk length of main umbel, number of umbellets of main umbel and main umbel fruit weight while the higher concentration of ethrel (1000 mg/l) decreased stalk length of main umbel, number of umbellets of main umbel as well as EO percentage and yield but significantly increased main umbel fruit weight and plant fruit yield (**Table 3**). The stimulatory effect of ethrel at 500 mg/l upon EO yield is in agreement with its effect in increasing both plant fruit yield and EO percentage. Krishnamoorthy (1981) also mentioned that ethylene content of cucumber (*Cucumis sativus* L.) plants were correlated with their sex expression, and application of ethylene increased the number of female

Table 4A Effect of pre-sowing seeds and ethrel treatments on yield characters, essential oil percentage and yield of fennel plants during harvest time.

Yield characters (harvest time)											Treatments	
Eoy (cc)	Eo (%)	Pfy	Sh/rr	Rdw	Shdw	Muy	Nu	Sl	Bn	Ph		
0.189	1.84	10.36	5.31	4.34	22.98	2.32	17.27	10.12	6.98	60.26	Control	Per-sowings seeds
0.229	1.92	11.97	5.70	4.37	24.49	2.69	18.45	12.15	7.85	63.38	Cooling	
0.245	1.95	12.71	5.11	5.24	26.76	2.80	20.71	12.99	8.54	72.79	Heating	
0.205	1.74	11.91	5.82	4.47	25.71	2.36	19.69	11.81	8.11	69.48	Soaking	
0.010	0.01	0.37	0.21	0.15	0.18	0.10	0.21	0.16	0.27	0.35	LSD 5%	
0.213	1.81	11.71	5.94	4.31	25.39	2.53	19.18	11.98	7.09	68.75	Control	Ethrel concentration
0.219	1.68	12.92	5.17	5.15	26.64	2.90	20.33	20.33	8.11	72.87	250	(mg/l)
0.230	1.91	12.05	5.11	4.80	25.47	2.61	20.01	20.01	8.50	65.65	500	
0.212	2.06	10.27	5.82	4.16	22.44	2.39	16.61	16.61	7.78	58.63	1000	
0.010	0.01	0.28	0.11	0.08	0.20	0.06	0.22	0.22	0.42	0.48	LSD 5%	

Values indicate the means of two seasons.
Ph = plant height, Bn = branch number/plant, Sl = stalk length of main umbel (cm), Nu = number of umbellets/umbel, Muy = main umbel yield, Shdw = fresh shoot weight (g/plant), Rdw = root dry weight, Sh/rr = shoot/root ratio (fw), Pfy = plant fruit yield (g), EO % = relative percentage essential oil (w/v), EOy = essential oil yield (ml)

Table 4B The combined effect of pre-sowing seeds and ethrel treatments on yield characters, essential oil percentage and yield of fennel plant during harvest time.

Combined treatments		Yield characters (harvest time)										
Pre-sowing treatment	Ethrel conc. (mg/l)	Ph	Bn	Sl	Nu	Muy	Shdw	Rdw	Sh/rr	Pfy	Eo (%)	Eoy (cc)
Control	0	57.45	5.80	9.52	14.08	1.71	20.59	3.38	5.09	7.92	1.71	0.136
	250	68.10	8.08	11.92	22.55	3.21	31.14	5.33	5.84	14.07	1.62	0.228
	500	64.25	7.26	10.43	20.19	3.02	21.24	4.62	4.60	11.34	2.03	0.230
	1000	51.32	6.76	8.63	16.97	2.84	18.94	4.04	4.70	9.19	1.99	0.183
Cooling	0	68.60	6.93	13.83	21.47	2.30	28.14	4.22	6.66	10.76	1.71	0.184
	250	69.87	7.77	12.82	16.95	2.12	26.19	4.88	5.37	12.75	1.63	0.208
	500	60.10	8.70	10.63	16.58	2.09	23.62	5.12	4.62	14.36	1.92	0.275
	1000	55.27	8.00	11.30	14.10	1.91	20.02	3.27	6.13	10.00	1.81	0.181
Heating	0	77.73	8.87	12.63	23.87	2.92	27.78	5.32	5.23	12.79	1.72	0.220
	250	79.49	8.97	12.88	20.44	2.64	26.66	5.25	5.08	13.05	1.83	0.238
	500	69.52	8.27	13.98	20.14	2.98	28.51	5.15	5.54	14.42	1.97	0.284
	1000	64.40	8.05	12.46	18.42	2.64	24.10	5.24	4.60	10.55	2.28	0.241
Soaking	0	71.53	6.75	11.92	21.90	2.65	25.66	4.33	5.79	11.75	1.90	0.223
	250	74.03	7.63	11.53	20.11	2.16	22.57	5.15	4.38	10.43	1.74	0.193
	500	68.75	9.78	11.04	19.82	2.33	28.50	4.33	6.59	14.13	1.81	0.255
	1000	63.61	8.29	12.27	16.95	2.15	26.68	4.08	6.54	10.27	2.14	0.220
LSD 5 %		0.95	0.84	0.45	0.43	0.12	0.41	0.16	0.23	0.57	0.02	0.010

Values indicate the means of two seasons.
Ph = plant height, Bn = branch number/plant, Sl = stalk length of main umbel (cm), Nu = number of umbellets/umbel, Muy = main umbel yield, Shdw = fresh shoot weight (g/plant), Rdw = root dry weight, Sh/rr = shoot/root ratio (fw), Pfy = plant fruit yield (g), EO % = relative percentage essential oil (w/v), EOy = essential oil yield (ml)

flowers and decreased the formation of male flowers; consequently the number of fruits also increased. The promotion of EO production due to ethrel application was observed by Arafa (1982) on some aromatic plants: fennel and chamomile (*Matricaria chamomila* L.) and by Kamel *et al.* (1989) on basil (*Ocimum basilicum* L.).

Concerning the combined effect, the data in **Table 3B** indicates that except for a few cases, all used combinations between pre-sowing seeds; cooling, heating as well as soaking in GA_3 and ethrel concentrations enhanced yield characters; soaking plants combined with either the lower or the moderate concentration of ethrel (250 and 500 mg/l) resulted in the highest stalk length of the main umbel, number of umbellets of the main umbel and main umbel fruit weight in comparison with untreated plants while the highest EO percentage resulted from the combination between cooled seeds with the lower concentration of ethrel (250 mg/l); in addition, heated seeds under the moderate concentration of ethrel (500 mg/l) recorded the highest EO yield followed by the combination (cooled seeds + 500 mg/l ethrel) and then the combination (soaked seeds + 500 mg/l). The accumulation of EO yield as a result of the combined effect of pre-sowing seed treatments and ethrel concentration may be due to their effect in increasing photosynthetic pigments as well as carbohydrate content as reflected in plant fruit yield.

Yield characters at harvest time

All pre-sowing treatments of seeds, i.e., cooling, heating and soaking in GA_3 (100 mg/l) caused a considerable increase in plant height, number of branches per plant, main umbel yield, number of umbellets of main umbel, stalk length of main umbel, dw of shoot and root, plant fruit yield as well as EO percentage and yield in most cases (**Table 4A**). This effect was more pronounced in heated seeds which recorded the highest yield characters values in most cases. Reda and Ashour (1974) in sugar beet (*Beta vulgaris* L. cv. 'Poly', AG, Poland) found that pre-sowing temperature treatments (cold and heat) resulted in a marked increase in the fw and dw of all plant organs. Also, fruit yield and weight of 100-fruits of cumin (*Cuminum cyminum* L.) plants were significantly increased by GA_3 application at 250 ppm (El-Keltawi *et al.* 2000).

Considering the effect of ethrel, the lower and moderate concentrations (250 and 500 mg/l) significantly increased the majority of yield characters since the lower concentration of ethrel resulted in the highest values of plant weight, main umbel yield, number of umbellets of main umbel, stalk length of main umbel, weight of shoot and plant fruit yield while the highest number of branches/plant and EO yield values were recorded by the moderate concentration. Although the higher concentration of ethrel (1000 mg/l) reduced the majority of yield characters, it resulted in the highest EO percentage. The changes in yield characters as affected by ethrel dose were almost in agreement with the changes in leaf pigments and carbohydrate content (**Table 2A**). The promotion of the number of umbels/plant, seed yield/umbel and seed yield/plant due to ethrel application had been noticed by Arafa (1982) and Helaly *et al*. (1984) on fennel plants.

Concerning the combined effect, except for a few cases, all combinations between pre-sowing seed treatments and

ethrel concentration caused a considerable increase in yield characters at harvest time in relation to untreated plants (**Table 4B**). Yield characters, plant height, number of umbellets/main umbel as well as weight of shoot and root showed significant increases as effected by all used combinations without a clear trend. At the same time, the tendency of the combined effect in increasing both plant fruit yield and EO yield followed nearly the same trend observed during the milky stage: heated seeds + ethrel (500 mg/l) > cooled seeds + 500 mg/l ethrel > soaked seeds + 500 mg/l ethrel.

CONCLUSIONS

Pre-sowing seed treatments of fennel plants with heating, cooling or soaking in GA_3 (100 mg/l) led to increases in growth characters, leaf pigments, total carbohydrate content, acceleration of flowering and ripening dates, plant fruit yield and EO yield, the effect becomes cumulative when pre-sowing seed treatments were used in combination with the moderate or lower concentration of ethrel (500 or 250 mg/l).

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