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Impact of Potassium Fertilization on Growth, Productivity, Potassium Use Efficiency and Volatile Oil of Fennel (*Feoniculum vulgare*, Mill) Plants Under Different Sowing Date

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Abstract: To study the impact of different potassium fertilization rates (0.0, 25, 50 and 75 kg K_2O/ feddan), sowing dates (1st October, 15th October, 1st November and 15th November) and their combinations on growth and productivity of fennel plants, a field experiment was done at privet Farm in Taha El-Marg Village, Diarb Nigm District, Sharkia Governorate, Egypt during 2021/2022 and 2022/2023 seasons. The findings indicated that fennel plants that were fertilized with a rate of 75 kg K_2O per feddan exhibited a substantial increase in plant height, number of branches per plant and total plant dry weight, in comparison to the other rates of potassium application. Moreover, the maximum values of yield components including umbels number per plant and fruit yield per plant and per feddan, volatile oil production including volatile oil percentage and fruit yield per plant and per feddan and total chlorophyll content and potassium percentage in leaves were produced with the same rate of potassium. In general, the most effective treatments in all assessed parameters of fennel were observed when the plants were sown on 15th October with significant differences with the other sowing dates under study. Fennel plants that were fertilized with either 75 or 50 kg K_2O per feddan and sowed on 15th October exhibited the highest fruit and volatile oil yield per feddan. Notably, there were no significant differences seen between the two fertilization levels. Finally, the recommended treatment of this study was fertilized plants with 50 kg K_2O/ feddan under 15th October sowing date under Sharkia Governorate conditions.

Key words: Fennel, sowing date, potassium, growth, fruit yield, volatile oil, chlorophyll.

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INTRODUCTION

Fennel (*Foeniculum vulgare* Mill), a member of the Apiaceae family, is a highly fragrant and medicinal plant that is native to North Africa, Asia, southern Europe and the Mediterranean Region (**Stary and Jirasek, 1975**). Antimicrobial and antioxidant activities of fennel have

also been pointed out by (**Ruberto *et al.*, 2000**). Leaves and leaf bases of fennel plant are utilized as a green salads and as a garnish and also eaten with snails and fish, while fruits have a pleasant, burning sweet taste, spicy odour, perfumery and pharmaceutical as well as food flavouring utilized (**Selim *et al*., 2013**). Fennel is utilized as popular flavouring agent in pastry confectionery culinary preparation and bread. In addition, the fruits and essential oil of fennel are utilized as stomachic, diuretic, stimulant, laxative, emmenagogue, aperitif, galactogoguo, expectorant to promote secretion and to relieve flatulence and spasms.

The total fennel cultivated area in 2020 in Egypt was 3611 feddan (716 feddan in new land and 2895 feddan in old land) which produced 4988 tons (888 tons from new land and 4100 tons from old land) with average 1.381 ton/feddan (1.240 tons / fad. in new land and 1.416 tons/ feddan in old land) according to **Statistics of the Ministry of Agriculture (2020)**.

Any crop's success in cultivation is influenced by a variety of factors. One of the crucial elements for the production system of many crops is the sowing date. The sowing date has a considerable impact on the growth and yield of plants as well as the concentration of active compounds in aromatic and medicinal herbs (**Ghani *et al.*, 2011**). The application of various sowing dates leads to variations in solar radiation, temperature and day length experienced by plant growth processes, hence influencing plant development, growth and yield **(Dadashi and Khajepour, 2004)**. Moreover, numerous researchers have conducted experiments to examine the impact of varying sowing dates on fennel plant growth and development. In this concern, **Ayub *et al.* (2008)**, **Abd El-Wahab and Mehasen (2009)**, **Selim *et al*. (2013)** and **Dhillon *et al.* (2019)** they noticed that the suitable sowing date has positive impact on fennel growth, fruit yield, volatile oil and its chemical constituents.

Potassium (K^+) is a vital nutrient for plants and is necessary for photosynthesis as well as growth and development. Additionally, it enhances the production of lipids, proteins, carbohydrates and transports sugars and cells and tissues of strengthen to guard against pathogens and pests **(Mengel and Kirkby, 1982)**. Furthermore, **Younis *et al.* (2010)** indicated that supplying fennel plants with 30 kg K_2O/feddan were effective on enhancing the essential oil and fruit yield productivity. **Hafiz and Ewis (2015)** found that using potassium level at 48 kg K_2O/feddan significantly increased fennel growth characters as well as improved yield and volatile oil productivity. Also, **Salama and Khater (2020)** reported that fertilized Dutch fennel plants with potassium gave the highest values of umbels number and fruit yield/ plant and/ feddan as well as volatile oil percentage and volatile oil yield/ plant and/ feddan.

The aim of the current experiment was to evaluate and assess the magnitude of applying potassium fertilization under different sowing date in enhancing the quality and quantity of *Foeniculum vulgare*, Mill plant, in terms of plant growth, fruit and volatile oil productivity as well as total chlorophyll, to increase its productivity under Sharkia Governorate conditions.

MATERIALS AND METHODS

A field experiment was conducted utilizing various potassium fertilization rates (0.0, 25, 50 and 75 kg K_2O/ feddan), various sowing dates (1st October, 15th October, 1st November and 15th November) and their combination treatments in order to improve fennel growth and productivity. During the winter seasons of 2021/2022 and 2022/2023, this experiment was conducted in privet Farm in Taha El–Marg Village, Diarb Nigm District, Sharkia Governorate, Egypt. Before sowing, a randomly selected soil sample was collected for physical and chemical analysis using the protocol described in Table 1 by **Chapman and Pratt (1978)**.

Table 1: Physical and chemical properties of experimental soil (average of the two seasons)

Physical analysis										Soil texture
Clay (%)			Silt (%)			Sand (%)				Clayly
56.37			32.36			11.27				
Chemical analysis										
pH	E.C. dSm^{-1}	Organic matter (%)	$CaCO_3$ (%)	Soluble cations (meq./ L)				Soluble anions (meq. /L)			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
8.08	3.14	0.71	0.52	13.19	10.70	2.93	4.08	0.00	11.86	3.84	15.23
Available nutrient (mg kg^{-1}soil)										
N		P	K		Fe		Zn		Cu	Mn	
46.17		21.13	198		1.92		0.76		0.68	0.48	

Fruits source and cultivation

The fennel fruits were bought at the Research Centre of Medicinal and Aromatic Plants, Dokky, Giza, Egypt. Each sowing date during the first and second seasons, fennel fruits (3-5 fruits/hill) was sown in the experimental plots. The experimental unit area was 16.80 m^2 (4 m 4.20 m) and was made up of 6 ridges that were 40 cm apart on either side of each ridge, each with two fennel plants. The ridges were spaced 70 cm apart.

Fertilization sources and rates

Fertilization rates for nitrogen and phosphorus were 60 kg/feddan and 31, respectively. The sources of nitrogen and phosphorus were calcium super phosphate (15.5 kg P_2O_5/feddan) and ammonium sulphate (20.5% N). In addition, potassium sulphate (48.5% K_2O) was used to apply the various potassium fertilization rates under study. All of the P fertilizer was added during the soil preparation. In the other hand, three equal applications of N and K fertilizer were made to the soil at 25, 50, and 75 days after the date of sowing. The normal agricultural practices for fennel plants were carried out as commonly followed in the district.

Experimental Design

Four sowing dates (1st October, 15th October, 1st November and 15th November) and four potassium rates (0.0, 25, 50 and 75 kg K_2O/ feddan) as soil application which were combined to create sixteen treatments in the experiment. Three replicates of these treatments were set up in a split plot design. In the main plots, the sowing dates were assigned and the potassium rates were assigned at random in the sub plots.

Data recorded

Plant growth

A random sample of three fennel plants from every treatment were randomly taken at 120 days after sowing in the two seasons (2021/2022 and 2022/2023) for measuring the following traits: Plant height (cm), branches number/ plant, aerial parts (branches+ leaves) and roots dry weight/ plant (g).

Yield components and K use efficiency

At harvest time (150 days after sowing) in the both seasons, three fennel plants of every plot were harvested and the following data were listed: Number of umbels per plant and fruit yield per plant (g). Then, total fruit yield /feddan (kg) was calculated.

The efficiency of potassium fertilizer was calculated according to **Clark (1982)** from the following formula:

$$KUE= KF - KC / R$$

Where, KUE is the fertilizer use efficiency in kg/kg, KF is the yield in the treated plot in kg/feddan, KC is the yield in the control plot in kg/feddan, and R is the amount of potassium applied in kg/feddan.

Volatile oil production

According to **Guenther (1961)**, the fennel air dried fruit volatile oil was isolated for 3 hours by hydro distillation after 150 days from the planting date in order to extract the volatile oil. Then, the yield of feenel volatile oil per plant (ml) and per feddan (l) was calculated.

Chemical constituents

After 120 days from the sowing date, fennel leaves (the upper 4 or 5 leaves in the plant) were measured for total chlorophyll content (a+ b mg/100 g as fresh weight) according to **Cherry (1973)**. Also, the determination of potassium percentage in fennel leaves was conducted using a flame photometer as reported by the methodology of **Brown and Lilleland (1946)**.

Statistical Analysis

This experiment utilized a split-plot experiment with a completely randomized block design for its statistical layout. According to **Gomez & Gomez (1984)**, data were evaluated. The means were compared using Statistix Version 9 (**Analytical software, 2008**) computer software.

RESULTS AND DISCUSSION

Plant growth

Data presented in Tables 2 and 3 reveals that, moderate sowing dates (15th October) significantly produced the maximum fennel height, more branches per plant and aerial parts and roots dry weights per plant compared to the other sowing dates under study in both seasons. Generally, the lowest values in fennel growth parameters were noticed when fruits of fennel were sown in the latest sowing date (15th November) compared to the other ones under study. The increases in number of branches/ plant and aerial dry weight / plant (as average of the two seasons) were about 0.55 and 1.71 for sowing date on 1st Oct ,2.92 and 17.87 for sowing date on 15th Oct. and 1 and 7.99 for sowing date on 1st Nov. over sowing date on 15th Nov., respectively. Moreover, these findings could also be the result of the reasonable sowing date, which offers a great chance to get higher vegetative growth parameters as the environmental conditions got more favorable. Also, **Abd El-Aleem *et al.* (2017)** and **Dhillon *et al.* (2019)** on fennel plants they noticed similar results.

Concern potassium fertilization effect, it appears that utilizing potassium at 75 kg K_2O/ feddan significantly increased growth traits of fennel compared to the other rates and control in both seasons (Tables 2 and 3). Furthermore, increasing potassium rates from 25 to 75 kg K_2O/ feddan gradually improved *Foeniculum vulgare* growth parameters. The increases in number of branches/ plant and aerial dry weight / plant (as average of the two seasons) were about 0.67 and 2.44 for K_2O at 25 kg / fed.,1.67 and 5.36 for K_2O at 50 kg/ fed. and 1.81 and 7.53 for K_2O at 75 kg / fed over the control (0 K_2O), respectively. Potassium fertilizers have demonstrated their importance in plant metabolism, water transport in xylem, cell elongation and the production of carbohydrates. Likewise, **Barzegar *et al.* (2020)** indicated that fertilized fennel plants with 100 or 150 kg K_2O/ hectare significantly improved growth parameters compared to control.

Results in Tables 2 and 3 show that, combination between sowing dates and potassium fertilization significantly enhanced growth traits of fennel compared to the later date (without potassium fertilization and planted in 15th November) in both seasons. However, the best combination treatment in plant height, branches number, vegetative and roots dry weights per plant were that of sowing at 15th October combined with potassium at 75 kg K_2O/ feddan. In general, as mentioned above, both sowing date and potassium fertilization (each alone) improved growth of fennel plant, in turn; they together might maximize their impacts leading to tallest plants, more branches as well as heaviest aerial and roots per plant. In the same time, **Abou El-Magd *et al.* (2010)** pointed out that the highest vegetative growth of fennel was recorded under the combination of early date and the highest potassium rate (75 kg K_2O/ feddan) under El Beheira Governorate, Egypt.

Table (2). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on plant height (cm) and number of branches per plant of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	25	50	75	Mean (S)
Plant height (cm)					
			2021/2022 season		
1st October	161.00	161.33	163.33	166.67	**163.08**
15th October	166.67	171.67	178.67	177.67	**173.67**
1st November	164.00	166.67	168.67	169.00	**167.08**
15th November	153.33	156.67	161.33	162.33	**158.42**
Mean (K)	**161.25**	**164.08**	**168.00**	**168.92**	
L.S.D. at 5 %	**(S)= 1.13**		**(K) = 0.88**	**(S×K) = 1.90**	
			2022/2023 season		
1st October	156.33	159.00	167.67	170.33	**163.33**
15th October	167.00	176.67	184.33	186.67	**178.67**
1st November	158.67	165.33	178.33	177.33	**169.92**
15th November	149.00	152.67	158.67	162.00	**155.58**
Mean (K)	**157.75**	**263.42**	**172.25**	**174.08**	
L.S.D. at 5 %	**(S)= 1.16**		**(K) = 1.06**	**(S×K) = 2.17**	
Number of branches per plant					
			2021/2022 season		
1st October	8.00	8.67	9.67	9.67	**9.00**
15th October	10.33	10.67	12.33	13.00	**11.58**
1st November	9.33	10.00	10.00	10.33	**9.92**
15th November	7.33	8.33	9.00	8.67	**8.33**
Mean (K)	**8.75**	**9.42**	**10.25**	**10.42**	
L.S.D. at 5 %	**(S) = 0.55**		**(K) = 0.50**	**(S×K) = 1.02**	
			2022/2023 season		
1st October	8.33	9.33	10.00	10.00	**9.42**
15th October	10.67	11.00	12.33	12.33	**11.58**
1st November	8.67	9.67	10.67	10.67	**9.92**
15th November	7.67	8.67	9.67	10.00	**9.00**
Mean (K)	**8.83**	**9.67**	**10.67**	**10.75**	
L.S.D. at 5 %	**(S) = 0.79**		**(K) = 0.54**	**(S×K) = 1.22**	

Table (3). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on aerial parts and roots dry weights per plant (g) of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	25	50	75	Mean (S)
Aerial parts dry weight/ plant (g)					
			2021/2022 season		
1st October	36.83	38.93	39.97	41.66	**39.35**
15th October	48.72	51.77	58.48	59.27	**54.56**
1st November	42.08	45.35	47.24	50.95	**46.41**
15th November	36.03	37.05	38.37	38.87	**37.58**
Mean (K)	**40.92**	**43.28**	**46.01**	**47.69**	
L.S.D. at 5 %	**(S)= 0.84**		**(K) = 0.80**	**(S×K) = 1.61**	
			2022/2023 season		
1st October	39.33	40.23	41.41	44.17	**41.29**
15th October	50.89	54.45	62.86	65.41	**58.40**
1st November	42.67	44.21	48.06	52.25	**46.80**
15th November	37.63	38.45	40.73	41.73	**39.64**
Mean (K)	**42.63**	**44.34**	**48.26**	**50.89**	
L.S.D. at 5 %	**(S)= 0.68**		**(K) = 0.57**	**(S×K) = 1.20**	
Roots dry weight/ plant (g)					
			2021/2022 season		
1st October	4.41	4.92	5.69	6.07	**5.27**
15th October	5.88	8.08	8.94	9.22	**8.03**
1st November	4.95	5.64	6.61	7.80	**6.25**
15th November	4.10	4.43	5.04	5.17	**4.69**
Mean (K)	**4.84**	**5.77**	**6.57**	**7.07**	
L.S.D. at 5 %	**(S) = 0.32**		**(K) = 0.29**	**(S×K) = 0.59**	
			2022/2023 season		
1st October	4.46	5.08	6.15	6.51	**5.55**
15th October	6.76	8.29	8.71	9.05	**8.20**
1st November	5.70	6.08	7.57	8.19	**6.89**
15th November	4.34	4.61	5.00	5.22	**4.79**
Mean (K)	**5.31**	**6.01**	**6.86**	**7.24**	
L.S.D. at 5 %	**(S) = 0.16**		**(K) = 0.20**	**(S×K) = 0.39**	

Yield components and potassium use efficiency (KUE)

Results presented in Tables 4 and 5 reveal that, in comparison to the other sowing dates under study, fennel fruits sown on 15th October significantly enhanced the number of umbels per plant, fruit yield per plant (g) and fruit yield per feddan (kg) in both seasons. Moreover, delaying the sowing date led to a significant decrease in fennel yield components. In addition, the decreases in fruit yield per feddan were about 135.10 kg and 163.75 kg/ feddan for 15th November lower the 15th October in 1st and 2nd seasons, respectively.

In the same line, **Meena *et al.* (2017)** revealed that sowing of dill on 15th October exhibited significantly maximum number of umbels per plant, seed yield /hectare. These results are in harmony with those found by **Abd El-Aleem *et al.* (2017)** and **Dhillon *et al.* (2019)** on fennel plants. Moreover, sown seeds of fennel on 1st October produced the highest values of potassium use efficiency (3.07 and 3.10 kg fruits/kg K_2O) in 1st and 2nd seasons, respectively. Furthermore, the sowing dates sequence regard KUE from top to less were October 15th > November 1st > October 1st > November 15th in both seasons (Table 6).

Increasing of potassium fertilization rate significantly improved the number of umbels/plant, fruit yield/plant and fruit yield/feddan of fennel plants (Tables 4 and 5). The highest values of fennel yield components were recorded with the highest rates of potassium fertilization (50 and 75 kg K_2O /fed.) without significant difference between them during both seasons. The increases in total fruit yield (as average of the two seasons) were about 70.29 for K_2O at 25 kg/ fed., 139.11 for K_2O at 50 kg/ fed. and 153.91 for K_2O at 75 kg/ fed. over the control (0 K_2O), respectively. The well-known roles of potassium in plant life, as discussed in the introduction, may be responsible for the stimulating effects of potassium application on fennel yield. Generally, according to **Abdelkader *et al*. (2018)**, any potassium rates significantly increased the number of umbels/plant and fruit yield per plant and per feddan of caraway compared to control in both seasons. With the maximum rate of potassium fertilization (50 kg K_2O/ feddan) applied throughout both seasons, the highest values of the yield components of caraway were noted. Potassium fertilization rat of 75 kg K_2O/ feddan significantly decreased potassium use efficiency (KUE) of fennel plant compared to the lowest and medium rate 25 and 50 kg K_2O /feddan during the two seasons (Table 6).

The best combination treatment in fennel yield components was that of sowing at 15th October combined with potassium fertilization at 75 kg K_2O/ feddan (Tables 4 and 5). However, combination between sowing dates and potassium rates significantly increased umbels number and fruit yield per plant and per feddan compared to the later date (sown in 15th November and without K fertilization) in the two consecutive seasons. In the same time, as mentioned above, both sowing date and potassium fertilization each alone increased yield components of fennel plant, in turn; they together might maximize their impacts leading to more umbels and yield per feddan. The simulative effect of the interaction between sowing date on 15th Oct. and 75kg K_2O/ fed. on total fruit yield may be due to that this treatment increased number of branches / plant (Table 2), dry weight of aerial parts (Table 3) and number of umbels / plant (Table 4). In the meantime, the best combination treatment concern potassium use efficiency was that of 1st October in the first season and 1st November in the second one combined with potassium fertilization at 25 kg K_2O/ feddan compared to the other combinations under study (Table 6). However, **Mekdad *et al.* (2021)** indicated that the interaction of 1st September sowing date × 525 kg $CaSO_4$ ha^{-1} maximized the potassium use efficiency of *Beta vulgaris*.

Table (4). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on number of umbels per plant and fruit yield per plant (g) of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	25	50	75	Mean (S)
Number of umbels per plant					
			2021/2022 season		
1st October	50.55	53.88	60.55	61.89	**56.72**
15th October	55.33	63.55	69.11	69.44	**64.36**
1st November	52.11	56.22	61.44	63.55	**58.33**
15th November	48.44	50.44	55.99	56.77	**52.91**
Mean (K)	**51.61**	**56.02**	**61.77**	**62.91**	
L.S.D. at 5 %	**(S)= 1.30**		**(K) = 0.71**	**(S×K) = 1.77**	
			2022/2023 season		
1st October	55.00	61.00	67.66	67.89	**62.89**
15th October	62.55	68.11	75.66	76.11	**70.61**
1st November	58.66	64.44	69.22	69.78	**65.53**
15th November	49.22	55.44	63.22	63.11	**57.75**
Mean (K)	**56.36**	**62.25**	**68.94**	**69.22**	
L.S.D. at 5 %	**(S)= 0.43**		**(K) = 0.84**	**(S×K) = 1.51**	
Fruit yield per plant (g)					
			2021/2022 season		
1st October	19.37	22.17	25.20	25.27	**23.00**
15th October	22.33	24.67	27.27	27.33	**25.40**
1st November	21.22	23.33	25.93	26.27	**24.19**
15th November	18.83	20.17	21.79	22.53	**20.83**
Mean (K)	**20.44**	**22.58**	**25.05**	**25.35**	
L.S.D. at 5 %	**(S) = 0.64**		**(K) = 0.37**	**(S×K) = 0.90**	
			2022/2023 season		
1st October	21.02	23.98	26.53	27.12	**24.66**
15th October	24.55	26.45	29.38	29.28	**27.42**
1st November	23.16	25.58	27.13	27.68	**25.89**
15th November	18.55	21.55	23.15	24.58	**21.96**
Mean (K)	**21.82**	**24.39**	**26.55**	**27.17**	
L.S.D. at 5 %	**(S) = 0.36**		**(K) = 0.54**	**(S×K) = 1.00**	

Table (5). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on fruit yield per feddan (kg) of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	25	50	75	Mean (S)
			2021/2022 season		
1st October	581.00	665.00	756.00	758.00	**690.00**
15th October	670.00	740.00	810.00	820.00	**760.00**
1st November	636.50	700.00	778.00	788.00	**725.63**
15th November	565.00	605.00	653.60	676.00	**624.90**
Mean (K)	**613.12**	**677.50**	**749.40**	**760.50**	
L.S.D. at 5 %	(S)= 18.01		(K) = 11.83	(S×K) = 27.19	
			2022/2023 season		
1st October	630.50	719.50	796.00	813.50	**739.87**
15th October	736.50	793.50	881.50	878.50	**822.50**
1st November	694.70	767.50	814.00	830.50	**776.67**
15th November	556.50	646.50	694.50	737.50	**658.75**
Mean (K)	**654.55**	**731.75**	**796.50**	**815.00**	
L.S.D. at 5 %	(S)= 10.71		(K) = 16.17	(S×K) = 29.95	

Table (6). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on potassium use efficiency (kg fruit/K kg) of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)			
	25	50	75	Mean (S)
		2021/2022 season		
1st October	3.36	3.50	2.36	**3.07**
15th October	2.80	2.96	2.00	**2.59**
1st November	2.54	2.83	2.02	**2.46**
15th November	2.60	1.77	1.48	**1.62**
Mean (K)	**2.58**	**2.77**	**1.97**	
L.S.D. at 5 %	(S)= 0.98	(K) = 0.29	(S×K) = 1.08	
		2022/2023 season		
1st October	3.56	3.31	2.44	**3.10**
15th October	2.28	2.90	1.89	**2.36**
1st November	2.91	2.39	1.81	**2.37**
15th November	3.60	2.76	2.41	**2.92**
Mean (K)	**3.09**	**2.84**	**2.14**	
L.S.D. at 5 %	(S)= N.S.	(K) = 0.48	(S×K) = 1.11	

Volatile oil production

Results recorded in Tables 7 and 8 demonstrate that, the moderate sowing date (15th October) significantly increased volatile oil percentage, yield per plant (ml) and yield per feddan (l) compared to the earliest and later sowing dates under study in both seasons. Furthermore, delaying sowing date from 15th October to 15th November gradually decreased fennel yield components in the 1st and 2nd seasons. Likewise, according to **Abdul-Hafeez *et al.* (2020)**, compared to fennel plants grown in the beginning and middle of November, fruits containing volatile oil from plants harvested in mid-October had the highest percentage of anethole and the lowest percentage of estragole.

As potassium fertilization rate increased volatile oil yield per plant and per feddan were gradually increased (Tables 7 and 8). The increases in volatile oil yield per feddan was 6.31 and 6.56 l/ feddan for 75 kg K_2O/feddan rate and 5.63 and 5.63 l/ feddan for 50 kg K_2O/feddan rate over control in the 1st and 2nd seasons, respectively. The best treatment in this connection was 75 kg K_2O/feddan compared to control and the other ones under study. According to **Hafiz and Ewis (2015),** fennel plants fertilized with 48 kg K_2O/feddan produced the highest oil output per plant and feddan during both seasons.

Table (7). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on volatile oil percentage and volatile oil yield per plant (ml) of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	**25**	**50**	**75**	**Mean (S)**
Volatile oil percentage					
2021/2022 season					
1st October	2.550	2.770	2.873	2.950	**2.786**
15th October	2.773	2.997	3.090	3.123	**2.996**
1st November	2.583	2.870	2.923	3.013	**2.848**
15th November	2.470	2.513	2.537	2.563	**2.521**
Mean (K)	**2.594**	**2.788**	**2.856**	**2.913**	
L.S.D. at 5 %	**(S)= 0.012**	**(K) = 0.014**		**(S×K) = 0.028**	
2022/2023 season					
1st October	2.587	2.903	2.990	3.017	**2.874**
15th October	2.927	3.103	3.117	3.163	**3.078**
1st November	2.773	2.977	2.973	3.040	**2.941**
15th November	2.457	2.580	2.570	2.637	**2.561**
Mean (K)	**2.686**	**2.891**	**2.913**	**2.964**	
L.S.D. at 5 %	**(S)= 0.031**	**(K) = 0.016**		**(S×K) = 0.042**	
Volatile oil yield per plant (ml)					
2021/2022 season					
1st October	0.494	0.614	0.724	0.745	**0.644**
15th October	0.619	0.739	0.842	0.853	**0.764**
1st November	0.548	0.670	0.758	0.791	**0.692**
15th November	0.465	0.507	0.553	0.578	**0.526**
Mean (K)	**0.532**	**0.633**	**0.719**	**0.742**	
L.S.D. at 5 %	**(S) = 0.019**	**(K) = 0.010**		**(S×K) = 0.025**	
2022/2023 season					
1st October	0.544	0.697	0.793	0.818	**0.713**
15th October	0.719	0.821	0.916	0.926	**0.845**
1st November	0.642	0.762	0.807	0.842	**0.763**
15th November	0.456	0.556	0.595	0.648	**0.564**
Mean (K)	**0.590**	**0.709**	**0.778**	**0.809**	
L.S.D. at 5 %	**(S) = 0.013**	**(K) = 0.017**		**(S×K) = 0.032**	

Going along with combination treatments among sowing dates and potassium fertilization, it was obvious from Tables 6 and 7 that combination of 15th October as sowing date + potassium fertilization at 75 kg K_2O/feddan rate resulted in significant increase in the volatile oil production of fennel plants over all other combined treatments. In contrast, the lowest values were recorded with control plants sown on 15th November without potassium application. The increases in volatile oil yield per feddan was 11.65 and 14.11 l/ feddan for 15th October sowing date + 75 kg K_2O/feddan and 11.32 and 13.79 l/ feddan for 15th October sowing date + 50 kg K_2O/feddan over control in the 1st and 2nd seasons, respectively, without significant difference between them. Moreover, **El-Shoura *et al.* (2019)** revealed that sowing sweet fennel fruits on 15th October produced the maximum essential oil yield per plant and per feddan as well as the highest results for the percentage of essential oil. It might be connected to the lengthening of the vegetative growth stage, which led to an increase in volatile oil production. Also, **Peçanha *et al.* (2023)** found that the essential oil yield of lavender plants was higher when K_2SO_4 was applied.

Chemical constituents

The data recorded in Table 9 indicate that sown seeds of fennel on 15th October and 1st November produced the highest values of total chlorophyll content a+ b (3.41 and 3.43 as well as 3.01 and 3.37 mg/100g as fresh weight) and potassium percentage in leaves (2.29 and 2.37 as well as 2.21 and 2.34 %) compared to the other sowing dates under study in 1st and 2nd seasons, respectively. When compared to the earlier sowing dates under study, the 15th November sowing date showed the lowest values in this regard. These results are in accordance with those demonstrated by **Barzegar *et al*. (2013)** on fennel, **El- Gamal and Ahmed (2016)** on dill and **Adamczewska-Sowinnska *et al*. (2021)** on quinoa plants.

Potassium percentage and total chlorophyll content of fennel leaves increased gradually with every increase of potassium fertilization rate from 25 to 75 kg K_2O/ feddan (Table 9). The highest values in potassium percentage and total chlorophyll content in fennel leaves were (2.27 and 2.31% as well as 3.72 and 3.43 mg/100g as fresh weight) for 75 kg K_2O/ feddan treatment compared to the other ones and control in the 1st and 2nd seasons, respectively. According to research by **Yin *et al*. (2023)**, applying K fertilizer judiciously can boost millet yield by increasing K utilization efficiency and accumulation in leaves.

Table (8). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on volatile oil yield per feddan (l) of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	**25**	**50**	**75**	**Mean (S)**
			2021/2022 season		
1st October	14.82	18.42	21.72	22.36	**19.33**
15th October	18.58	22.18	25.28	25.61	**22.91**
1st November	16.44	20.09	22.74	23.75	**20.76**
15th November	13.96	15.21	16.58	17.33	**15.77**
Mean (K)	**15.95**	**18.97**	**21.58**	**22.26**	
L.S.D. at 5 %	**(S)= 0.57**		**(K) = 0.29**	**(S×K) = 0.75**	
			2022/2023 season		
1st October	16.31	20.89	23.80	24.55	**21.39**
15th October	21.56	24.63	27.47	27.79	**25.36**
1st November	19.27	22.85	24.20	25.25	**22.89**
15th November	13.68	16.68	17.85	19.45	**16.91**
Mean (K)	**17.70**	**21.26**	**23.33**	**24.26**	
L.S.D. at 5 %	**(S)= 0.38**		**(K) = 0.51**	**(S×K) = 0.96**	

Table 9 shows that the best combination treatment regards potassium percentage and total chlorophyll content in fennel leaves were that of sowing on 15th October combined with potassium fertilization at 75 kg K_2O/ feddan. However, combination between sowing dates and potassium fertilization rates significantly increased potassium percentage and total chlorophyll content compared to the later date (sown in 15th November and without potassium application) in the two seasons.

Table (9). Effect of sowing date (S), potassium fertilizer rate (K) and their combinations (S × K) on total chlorophyll content a+ b (mg/100g as fresh weight) and potassium percentage of fennel (*Feoniculum vulgare*, Mill) during 2021/2022 and 2022/2023 seasons

Sowing date	Potassium fertilizer rate (kg/feddan)				
	0.0	25	50	75	Mean (S)
Total chlorophyll content a+ b (mg/100g as fresh weight)					
			2021/2022 season		
1st October	2.79	2.88	3.11	3.24	**3.00**
15th October	3.03	3.35	3.55	3.72	**3.41**
1st November	2.83	2.98	3.04	3.18	**3.01**
15th November	2.70	2.74	2.86	2.95	**2.81**
Mean (K)	**2.84**	**2.99**	**3.14**	**3.27**	
L.S.D. at 5 %	**(S)= 0.07**		**(K) = 0.06**	**(S×K) = 0.12**	
			2022/2023 season		
1st October	2.91	3.02	3.19	3.25	**3.09**
15th October	3.09	3.29	3.64	3.71	**3.43**
1st November	3.03	3.31	3.51	3.64	**3.37**
15th November	2.87	2.95	3.13	3.13	**3.02**
Mean (K)	**2.97**	**3.14**	**3.37**	**3.43**	
L.S.D. at 5 %	**(S)= 0.05**		**(K) = 0.06**	**(S×K) = 0.12**	
Potassium percentage in leaves					
			2021/2022 season		
1st October	2.02	2.12	2.19	2.21	**2.14**
15th October	2.15	2.30	2.34	2.38	**2.29**
1st November	2.06	2.16	2.29	2.33	**2.21**
15th November	1.94	2.11	2.16	2.17	**2.10**
Mean (K)	**2.04**	**2.17**	**2.24**	**2.27**	
L.S.D. at 5 %	**(S) = 0.02**		**(K) = 0.02**	**(S×K) = 0.04**	
			2022/2023 season		
1st October	2.12	2.12	2.19	2.22	**2.16**
15th October	2.25	2.36	2.43	2.43	**2.37**
1st November	2.22	2.29	2.39	2.40	**2.34**
15th November	2.04	2.07	2.14	2.17	**2.11**
Mean (K)	**2.16**	**2.21**	**2.29**	**2.31**	
L.S.D. at 5 %	**(S) = 0.01**		**(K) = 0.01**	**(S×K) = 0.02**	

Conclusion

Sowing fennel fruits in 15th October significantly improved fruit and volatile oil yield per feddan. In addition, higher rate of potassium fertilization (75 kg K_2O/ feddan) significantly affected fennel productivity. Generally, given the results of the study, for improving production of fennel fruits under conditions of Sharkia Governorate, Egypt it is recommended to sow on 15th October and fertilize with potassium at 50 kg K_2O per feddan.

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