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Effect of the Variation in Vernalization Temperature and Gibberellic Acid Concentration on Coriander Productivity

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Abstract

Compared to the other plants of family *Apiaceae*, production of coriander fruits requires longer periods. Thus, controlling of flowering duration and shorten the period is considered a crucial act to reduce the production period with save irrigation water. Therefore, an experiment was conducted during the two successive seasons (2018/2019 and 2019/2020) to investigate the effect of vernalization by four different temperatures (control without cold, 0° C, 3° C and 6° C) and three concentrations of gibberellic acid, GA_3, (0, 50 and 100 ppm) on vegetative growth, number of days to 50% flowering and maturity, fruits production and volatile oil percentage of coriander fruits. The experimental design was a Split-plot design with three replications. Results showed that the vernalized seeds at 3° C caused high significant effect on all studied characteristics where it gave the highest average of plant height, number of branches and umbls /, fruits yield, volatile oil percentages and oil yield (ml / plant), and reduction number of days to 50% flowering and maturity compared with other treatments. The application of GA_3 at 100 ppm gave the highest average in above-stated parameters compared to other GA_3 treatments. Concerning the effect of interaction treatments, the obtained results cleared that all studied characteristics showed the highest average as a result of the combination between vernalized seed at 3° C and 100 ppm of gibberellic acid (GA_3). Treatments under study gave a pronounced effect on essential constituents where linalool is the main constituent. In conclusion, to decrease the number of days from planting to complete maturity and increased dry herb weight/plant vernalized seeds at 3° C treated with GA_3 at 100 ppm should be exploited in coriander production systems.

Keywords*:* vernalization; coriander; yield; flowering; maturity; linalool; GA_3.

1. Introduction

Coriander plant (*Coriandrum sativum* L.) from family Apiaceae (Umberiferae) is an annual herbaceous plant, the herb and fruits of coriander have a pleasant aromatic flavor and thus is indispensable food adjunction in Egypt cookery. It has been used in medicine for thousands of years and the first uses of coriander in medicine were by the ancient Egyptians. The immense uses of coriander depend on the choice of fruits or green herbs, which are linked to their chemical compositions. The most important constituents are the essential and fatty oils. The seeds contain a volatile oil, which contains monoterpenoid like α-pinene and linalool (the main component is approximately 70% of the volatile oil), and the linalool may be muscle-relaxing and have pain-relieving effects through additional distinctive mechanisms. The seeds are mainly responsible for the medical use of coriander and have been used as a drug for indigestion, pain in the joints, rheumatism and against worms and have been recommended for dyspeptic complaints, loss of appetite, convulsion, insomnia and anxiety [1].

Gibberellic acid (GA_3) has the capability of modifying the growth pattern of treated plants by affecting the RNA and DNA levels, expansion and cell division, biosynthesis of enzymes, proteins, carbohydrates and photosynthetic pigments [2]. The application of different levels of gibberellin increased the growth parameters of plants, number of flowers and initiates early flowering as well as decreased number of days to 50% flowering and maturity gradually with an increasing level of GA_3 from 25 and 50 ppm in coriander plant [3,4, 5 and 6].

Vernalization is a process in which the ability to flower in plants is stimulated or accelerated by

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prolonged exposure of plants or seeds to low temperatures during cold of winter or by other artificial methods. Vernalization is the requirement of a period of exposure to low temperatures for the transition of plant apical meristem from the vegetative stage to the reproductive stage [7 and 8]. Coriander fruits production have longer periods compared to the fruits of other plants in the same family. Controlling of flowering duration and shorten the period required for coriander fruits production are important to reduce the production period and provide irrigation water for other crops. There are many factors affecting bolting and flowering for the coriander fruits production. Vernalization temperature and gibbrillic acid concentration are the most important factors affected bolting and flowering [4, 9 and 10].

Therefore, the present investigation was undertaken with the following objectives: to determine the optimum Vernalization temperature, appropriate concentration of GA_3 and the suitable combination of Vernalization temperature and GA_3 on vegetative growth decreased number of days to 50% flowering and maturity, fruits production and volatile oil percentage in coriander fruits.

2. Experimental

A field experiment was carried out to determine the effect of vernalization and application of gibberellic acid (GA_3) and their interaction on vegetative growth, decreased number of days to 50% flowering and maturity, fruits production and volatile oil percentage in coriander fruits, during the two successive seasons of 2018/2019 and 2019/2020 at the Agricultural Experimental Station of the National Research Centre at Nubaria, Beheira Governorate, Egypt. This experiment included 12 treatments that were arranged in a split plot design with three replicates. Vernalization temperature (Control without cooling, 0° C, 3° C and 6°C for four weeks) was placed in main plots and GA_3 treatments are distributed in sub plots at three levels of control (without GA_3), 50 and 100 ppm. The seeds were soaked in GA_3 solutions for 24 hours before cooling and the plants were sprayed in the morning at after three weeks from sowing. The soil of the experiments was sandy, the mechanical and chemical analysis of the soil were carried out before sowing according to [11] and presented in (Table (1).

Coriander fruits were kindly supplied from Department of Medicinal and Aromatic Plants, of Hort. Res. Inst., Agric. Res. Center Giza, Egypt. Fruits were sown directly after four weeks from cooling in soil on first November during the two successive seasons. The distance between ridges was 60 cm and distance between plants in the same ridge was 25 cm in the middle of the ridge below the points. About 5-7 fruits were sown per hill, and then thinned after two weeks to three plants / hill. All agricultural practices were carried out as recommended by Egyptian Ministry of Agriculture and Land Reclamation.

The plants in each plot were observed for dates to initiation of flowering and dates of flowering on 50 percentage plants in each plot were recorded. Based on the date, days taken to initiation of flowering and to 50 percentage flowering were worked out for each plot. As well as, at harvest stage when the secondary umbels colour was changed to green-yellow in each treatment, the five plants from each plot were randomly selected and data on particular parameters were measured and average was computed in both seasons to evaluate the following characters. Vegetative growth: plant height (cm), number of branches per plant and plant dry weight (g). Fruits measurements: number of umbels /plant, seed index (1000 fruits weight g), fruits yield (g /plant) and (kg /fed).

Volatile oil determination: oil percentage was determined by hydro distillation in Clevenger apparatus according to the method described by [12]. The volatile oil yield per plant (ml) was calculated by multiplying volatile oil percentage by fruit yield per plant. were dehydrated over anhydrous sodium sulphate and stored in refrigerator until analyzed. Oil composition of the first season was carried out by using Gas Liquid Chromatography Technique (GLC).

GLC was carried out at the Medicinal and Aromatic Dept., Horti. Res. Inst., Agric. Res. Center, Dokki. At the end, The data were statistically analyzed on split plot design by statistical software MSTAT-C and the means were compared by LSD Test at 5% level in the two growing seasons was carried out.

Table 1: Some physical and chemical properties of the soil used.

	Mechanical analysis				Chemical analysis						
					m. equivalent/100g soil						
Components	Sand %	Silt %	Clay %	Texture Class	PH	HCO_3	Cl^-	Ca^{+2}	Mg^{+2}	Na^+	K^+
Value	72.3	18.7	9	Sandy	7.5	2.3	0.8	3.2	1.2	1.1	0.25

3. Results and discussion

3.1. Plant height (cm) and branches number / plant:

The results in Table 2 revealed that coriander plant height and branch numbers per plant at harvest significantly increased as a result of vernalized seeds compared to non-vernalizedone. Furthermore, vernalized seeds at 3°C recorded the highest increments of coriander plants height and branches number per plant compared with the other rates (zero or 6°C) under study and control during the two seasons.

The plant height and number of branches / plant recorded at harvest varied significantly due to application of GA3 (Table 2). The maximum plant height and number of branches / plant were observed in GA3 at 100 ppm treatment, which was statistically parallel with GA3 at 50 ppm treatment while the minimum plant height and number of branches / plant were obtained from untreated plants.

Generally, results in Table (2) illustrate that, the interaction treatments between all temperatures of vernalized seeds with GA_3 concentrations increased plant height and branches number / plant compared to the control in both seasons. Furthermore, the best interaction treatment in this concern was that of vernalized seeds at 3° C interacted with GA_3 concentration at 100 ppm. Also, all interaction treatments were higher than individual vernalized seeds or individual GA_3 concentrations.

3.2. Days to initiation of flowering and days to 50% flowering:

The obtained results in Table 3 demonstrate that all temperatures of vernalized seeds decreased days to initiation of flowering and days to 50% flowering of coriander plant. In addition, vernalized seeds at 3° C or 6° C gave significant differences compared to vernalized seeds at 0° C or non-vernalized seeds, in most cases. Moreover, the vernalized seeds at 3° C recorded the lowest values in this connection.

Data in Table 3 reveal that days to initiation of flowering and days to 50% flowering of coriander plant decreased by increasing GA_3 rates. Likewise, the two GA_3 rates gave significant decreases in this respect compared to control during the two seasons. Also, the lowest values in this concern were achieved by the GA_3 rate of 100 ppm compared to control in the two seasons.

With regard to the interactive effects between all temperatures of vernalized seeds with GA3 concentrations decreased days to initiation of flowering and days to 50% flowering of coriander plant as compared with the control (Table 3). Vernalized seeds at 0°C, 3°C or 6°C resulted in significant decreases in above mentioned characteristics under different levels of GA_3 rates compared to control. In addition, the highest values in this connection were recorded under the effect of interaction treatments between vernalized seeds at 3°C and GA_3 concentrations at 50 or 100 ppm in first and second seasons, with significant decrease compared to control.

3.3. Fruits maturity and herb dry weight/plant:

Application of vernalized coriander seeds significantly promoted early fruits maturity and increased herb dry weight/plant as compared to non-vernalized seeds during both seasons (Table, 4). Vernalized seeds at 3°C, had the shortest number of days on complete maturity (122.22 and 124.11 days in both seasons, respectively) and heaviest dry herb weight/plant (16.94 and 17.78 g /plant in the two seasons, respectively), while non-vernalized seeds had longest days number on complete maturity (146.56 and 148.33 days in both seasons, respectively) and lightest dry herb weight/plant (10.94 and 12.72 g/plant in the two seasons, respectively). Data presented in Table indicated that the best-vernalized seeds were at 3° C, followed by 6° C, then 0° C in above-mentioned characteristics.

Table 4: Effect of vernalization and gibberellic acid treatments on days to maturity and herb dry weight (g / plant) of coriander plant during both seasons.

Temperature	Gibberellic acid (GA3) concentration							
	0.0	50 ppm	100 Ppm	Mean (C)	0.0	50 ppm	100 ppm	Mean (C)
	Days to maturity				Herb dry weight / plant (g)			
	First season (2018/2019)							
Control	150.67	145.00	144.00	146.56	10.17	10.83	11.83	10.94
0°C	143.33	140.00	136.00	139.78	12.33	13.50	13.83	13.22
3°C	124.67	122.00	120.00	122.22	16.17	16.83	17.83	16.94
6°C	144.00	143.33	141.00	142.78	13.17	14.33	15.17	14.22
Mean(G)	140.67	137.58	135.25		12.96	13.88	14.67	
LSD at 5 %	C=2.53 G=2.03 CxG=4.12				C=1.24 G=1.81 CxG=2.92			
	Second season (2019/2020)							
Control	152.33	147.00	145.67	148.33	11.83	12.83	13.50	12.72
0°C	145.00	142.33	138.00	141.78	14.54	15.00	15.17	14.90
3°C	126.67	124.00	121.67	124.11	17.50	17.83	18.00	17.78
6°C	146.00	145.33	143.00	144.78	14.33	14.83	15.83	15.00
Mean(G)	142.50	139.67	137.08		14.42	15.08	15.71	
LSD at 5 %	C=2.64 G=2.28 CxG=4.31				C=1.61 G=1.25 CxG=2.54			

Data in Tab. 4 show that there was a significant effect due to the interaction between vernalized seeds and GA_3 treatments on early maturity and dry herb weight/plant of coriander plant. In this connection, the combined vernalized seeds at 3° C together with GA_3 at 50 or 100 ppm significantly achieved the decrease in number of days from planting complete maturity and increased dry herb weight/plant compared to other combination or control in both seasons. However, the high decrease in number of days from planting to complete maturity and high increased dry herb weight/plant were achieved in vernalized seeds at 3° C treated with GA_3 at 100 ppm.

3.4. Fruits characters

The data presented in Tables 5 and 6 indicated a considerable variation for the number of umbels/plant, fruit yield/hill (g), fruit index, and fruit yield / fed. (Kg) in all vernalized seeds different temperatures over control. Application of vernalized seeds at 3° C led to significant increase and maximum values of number of umbels/plant, fruit yield/hill (g), fruit index, and fruit yield / fed. (Kg) followed vernalized seeds at 6° C, then vernalized seeds at 0° C in both season. Also, the above-mentioned parameters were significantly increased when vernalized seeds at 3° C compared to vernalized seeds at 0° C or 6° C in both seasons.

The obtained data in Tables 5 and 6 revealed that the application of plant growth regulator (GA_3) increased the number of umbels/plant, fruit yield/hill (g), fruit index, and fruit yield / fed. (Kg). The highest number of umbels/plant and fruit index the heaviest fruit yield/hill (g) and fruit yield / fed. (Kg) were recorded from 100 ppm GA_3 treatment followed by 50 ppm GA3 treatment and the minimum in the above-stated Characteristics was obtained from the control. Interaction treatments between vernalized seeds and GA_3 caused significant effect on growth characters (Table 5 and 6). In this regard, the interaction between vernalized seeds and GA_3increased number umbels/plant, fruit yield/hill (g), fruit index, and fruit yield (fed.) in both seasons. Also, the same treatments and the interaction of vernalized seeds at 3° C + GA_3 at 50 or 100 ppm recorded the highest number of umbels/plant and fruit index, the heaviest yield of fruits (per hill and per fed.) significant differences among these recorded treatments during two seasons. According to these results and from an economic point of view it is better to vernalize seeds at 3° C and them with GA_3 at 100 ppm to gain the maximum fruit yield of coriander plants.

3.5. Volatile oil percentage and yield (ml/plant):

Recorded data in Table 7 indicate that, in most cases, under the three temperatures of vernalized seeds (0° C, 3° C and 6° C) significant increment in coriander oil (volatile oil percentage and volatile oil yield as ml / plant) as compared to control during were recorded both seasons. Moreover, vernalized at 3° C gave the highest coriander oil with a significant difference, when compared to other vernalization temperatures. In addition, the highest percentages of coriander essential oil (0.41 and 0.43 %) were obtained when seeds vernalized at 3° C followed by seeds vernalized at 6° C and 0° C (0.34 and 0.36%) during the first and second seasons, respectively. The highest volatile oil yield per plant (0.131 and 0.147 ml/plant) was obtained as a result of 3° C followed by 6° C (0.109 and 0.126 ml/plant) then 0° C (0.109 and 0.119 ml/plant) in both seasons, respectively.

Table 5 Effect of vernalization and GA_3 treatments on number of umbels / plant and fruit yield / hill (g) of coriander plants during both seasons.

Temperature	Gibberellic acid (GA_3) concentration							
	0.0	50 ppm	100 ppm	Mean (C)	0.0	50 ppm	100 ppm	Mean (C)
	Number of umbels / plant				Fruit yield / hill (g)			
	First season (2018/2019)							
Control	24.67	28.33	32.00	28.33	25.17	28.33	29.83	27.78
0°C	30.33	33.33	34.67	32.78	27.17	29.33	30.83	29.11
3°C	37.67	38.33	40.67	38.89	29.83	32.33	33.83	32.00
6°C	33.00	34.67	36.00	34.56	28.17	29.67	31.33	29.72
Mean(G)	31.42	33.67	35.83		27.58	29.92	31.46	
LSD at 5 %	C=2.12 G=2.70 CxG=5.52				C=1.91 G=1.23 CxG=2.45			
	Second season (2019/2020)							
Control	27.33	31.67	34.33	31.11	27.67	30.83	32.17	30.22
0°C	32.67	35.33	37.67	35.22	27.50	31.67	32.33	30.50
3°C	40.00	41.00	42.67	41.22	32.17	34.83	36.17	34.39
6°C	36.00	36.67	39.00	37.22	30.67	32.17	33.67	32.17
Mean(G)	34.00	36.17	38.42		29.50	32.38	33.58	
LSD at 5 %	C=2.66 G=2.30 CxG=4.35				C=2.00 G=1.92 CxG=4.00			

Table 6 Effect of vernalization and GA_3 treatments on Fruit index and Fruit yield / fed. (Kg) of coriander plants during both seasons.

Temperature	Gibberellic acid (GA_3) concentration							
	0.0	50 ppm	100 ppm	Mean (C)	0.0	50 ppm	100 ppm	Mean (C)
	Fruit index (1000-fruit weight)				Fruit yield / fed.(kg)			
	First season (2018/2019)							
Control	11.17	11.33	11.50	11.33	671.09	755.54	795.54	740.72
0°C	11.67	11.83	12.17	11.89	724.43	782.20	822.20	776.28
3°C	13.17	13.33	13.50	13.33	795.54	862.20	902.20	853.31
6°C	12.33	12.50	12.67	12.50	751.09	791.09	835.53	792.57
Mean(G)	12.08	12.25	12.46		735.54	797.76	838.87	
LSD at 5 %	C=0.92 G=0.79 CxG=1.85				C=32.79 G=28.39 CxG=55.81			
	Second season (2019/2020)							
Control	10.33	10.50	10.83	10.56	737.76	822.20	857.76	805.91
0°C	11.17	11.33	11.67	11.39	733.32	844.42	862.20	813.31
3°C	12.33	12.50	12.83	12.56	857.76	928.87	964.42	917.01
6°C	11.50	11.67	11.83	11.67	817.76	857.76	897.76	857.76
Mean(G)	11.33	11.50	11.79		786.65	863.31	895.53	
LSD at 5 %	C=0.58 G=0.62 CxG=1.25				C=41.28 G=34.42 CxG=65.32			

The percentage of volatile oil and oil yield (ml/plant) analysis to evaluate the effect of GA_3 on coriander active constituents are presented in Table 7. Both concentrations of GA_3 (50 and 100 ppm) promoted accumulation of volatile oil (as a percentage) with the superiority of GA_3 at 100 ppm but not enough to result in significant differences. The highest percentages of coriander essential oil (0.36 and 0.38 %) were obtained when plants treated with GA_3 at 100 ppm followed by GA_3 at 50 ppm (0.35 and 0.37%) in the first and second seasons, respectively. Volatile oil yield (ml/plant) was significantly affected by the application of GA_3 at 50 and 100 ppm while the highest volatile oil yield per plant (0.115 and 0.129 ml/plant) was of 100 ppm GA_3 (0.115 and 0.129 ml/plant) followed by 50 ppm GA_3 (0.106 and 0.120 ml/plant) in both seasons, respectively.

Data in Tab. 7 show that there was a significant effect due to the interaction between different vernalized seeds (0° C, 3° C and 6° C) and GA_3 (50 and 100 ppm)) on essential oil % and yield. Data reveal that vernalized seeds at 3° C and treated with GA_3 at 100 ppm produced the highest volatile oil percent (0.41 and 0.43 %) and oil yield (0.145 and 0.160 ml /plant), respectively, followed by vernalized seeds at 3° C and treated with GA3 at 50 ppm but not enough to result in significant differences, in both seasons. There are significant differences between vernalized seeds at 3° C+ GA_3 and vernalized seeds at 0° C or 6° C + GA_3 in the above-mentioned traits.

3.6. Volatile oil constituents:

The main components of coriander seeds volatile oil at different treatments were determined qualitatively and quantitively by GLC where ten main components were identified. Total identified main components ranged from 94.77 to 98.49 %. The total oxygenated compounds were the dominant compounds where they ranged from 77.25 to 85.89 % while, total hydrocarbon compounds recorded 10.84 – 19.45. The 1st major compound was linalool (68.22 – 76.71 % followed by ß-Pinene (4.51 – 8.34%). The 3rd one was α- pinene (2.74 - 6.17).

The obtained results by Gas chromatographic analysis in Table 8 pointed out that the different vernalization temperatures caused differences in the constituents of the volatile oil of coriander plant (α-pinene, Camphene, Sabinene, ß-Pinene, P-Cymene, linalool, Geraniol, Borneol, Linalyl acetate and geranyl acetate). Vernalized seeds at 3° C gave the highest values of α-pinene, ß-Pinene and linalool compared to vernalized seeds at 0° C or 6° C.

In the same Table ten components of coriander volatile oil were identified and quantified for the first season samples was influenced by the application of GA_3. The application of GA_3 at 50 or 100 ppm improved the quality of coriander essential oil by increment of the major component (linalool) percentage in oil compared to control. Moreover, interaction of vernalized seeds at 0° C, 3° C or 6° C with application of GA_3 at 50 or 100 ppm increased the major component (linalool) of coriander volatile oil compared to control. At the same time, the interaction between vernalized seeds at 3° C with GA_3 at 100 ppm gave the highest values of major component (linalool) of coriander volatile oil compared to control or other treatments.

4. Discussion

It is well known that, vernalization is a process in which the ability to flower in plants is stimulated or accelerated by prolonged exposure of plants or seeds to low temperatures during cold of winter or by other artificial methods. Vernalized seeds at 3°C recorded the highest increments for coriander plants height and branches number per plant compared with the other rates under study (zero or 6°C) (Table 2). However, a positive influence of vernalization has been noticed on the plant height, leaves number of onion [8]. In addition, [7] noticed that vernalized seeds significantly increased height and number of branches for *Hibiscus sabdariffa*.

Also, gibberellic acid (GA3) has the capability of modifying the growth pattern of treated plants by affecting the RNA and DNA levels, cell expansion and cell division, biosynthesis of enzymes, protein, carbohydrates and photosynthetic pigments [13, 7 and 14]. The application of different levels of gibberellin increased plant height and branch numbers per plant at harvest. In this respect, the maximum plant height and number of branches / plant were observed in GA_3 at 100 ppm treatment, which was statistically parallel with GA_3 at 50 ppm treatment while the minimum plant height and number of branches / plant were obtained from untreated plants. Gibberellin increases plant height and number of branches in the plant by stimulating cell division and elongation [15]. These results might be due to the gibberellins has a major role in cell division and in increasing its absorption of water and then in an enlargement of its size by increasing its protoplasmic content which is reflected in the surface area of the plant and its tissues, size and length. These results are in harmony with those obtained by [3, 5, 16, 17 and 18] on coriander plant. Generally, results illustrate that the interaction treatments between all temperatures of vernalized seeds with GA_3 concentrations increased coriander plant height and branch number/plant compared to the control in both seasons. Furthermore, the best interaction treatment in this concern was that of vernalized seeds at 3° C interacted with GA_3 concentration at 100 ppm. Also, all interaction treatments were higher than individual vernalized seeds or individual GA_3 concentrations. Moreover, as mentioned above, both vernalized seeds with GA_3 concentrations maximize their effects leading to taller plant and more branches; this is due to that vernalized seeds are not only for initiating GA_3 biosynthesis in a vegetative plant but also elevating the GA_3 sensitivity of the plants [5]. Furthermore, the interaction between vernalized seeds and 150 ppm gibberellins recorded the highest values in most characteristics studied [21].

In the most cases vernalized seeds at 3° C or 6° C gave significant differences on days to initiation of flowering and days to 50% flowering compared to vernalized seeds at 0° C or non-vernalized seeds (Table 3). Moreover, the vernalized seeds at 3° C recorded the lowest values in this connection.

Vernalization just works as the first step to obtain the The initiation of flowering and Days to 50 per cent flowering decreased gradually with an increasing level of GA_3 which indicated its involvement in transition of vegetative apices to floral apices [4]. These results are in agreement with those reported by [20 and 28], where they mentioned that the application of GA_3 significantly affect the time of fifty percent flowering in coriander plant. With regard to the interactive effects between all temperatures of vernalized seeds with GA_3 concentrations decreased days to initiation of flowering and days to 50% flowering of coriander plant as compared with the control. Vernalized seeds at 0°C, 3°C or 6°C resulted in significant decreases in above mentioned characteristics under different levels of GA_3 rates in compared to control. In addition, the highest values in this connection were recorded under the effect of interaction treatments between vernalized seeds at 3°C and GA_3 concentrations at 50 or 100 ppm in first and second seasons, with significant decrease compared to control. competence to flower and early flowering for long day plants "such as coriander". The results indicated that vernalization could affect flowering through microRNA mechanism in Chinese cabbage [19]. Results also revealed that days to initiation of flowering and days to 50% flowering of coriander plant decreased by increasing GA_3 rates. Likewise, the two GA_3 rates gave significant decreases in this respect compared to control. Also, the lowest values in this concern were achieved by the GA_3 rate of 100 ppm compared to control in both seasons. Similar results were reported by [15] who noticed that the flowering time of vernalized plants was significantly reduced compared with the non-vernalized plants under various GA_3 concentrations.

In this respect, vernalized seeds at 3°C, had the lowest days number to complete maturity and get the heaviest dry herb weight/plant, while non-vernalized seeds had the longest days number to complete maturity and lightest dry herb weight/plant (Table 4). Data also, indicated that the best-vernalized seeds were at 3° C, followed by 6° C, then 0° C in above-mentioned characteristics. The reason for earliness in maturity and heaviest dry herb weight/plant might be due to vernalized seeds become physiologically more active and enable to synthesize required amount of hormones, and vernalized seeds led to greater efficiency in the flowering induction and reduction of the crop cycle [20]. Data recorded that GA_3 treatments significantly affected on number days to complete maturity. On the other hand the effect of GA_3 treatments on dry herb weight/plant was insignificantly. Furthermore, GA_3 at 100 ppm caused a decrement in the time required from planting to complete maturity and gave the highest values of dry herb weight per plant comparing with that scored from plants which received 50 ppm. These results were in conformity with the findings by [5, 16 and 10] in coriander indicated that herb dry weight increased and the number of days for maturity decreased gradually with an increasing level of GA_3 from 50 ppm to 75 ppm. These results are in harmony with those obtained by [22, 23 and 6]. In this connection, the combined vernalized seeds at 3° C together with GA_3 at 50 or 100 ppm significantly achieved the decrement from days number from planting to complete maturity and increased dry herb weight/plant compared to other combinations or control during both seasons. However, the highest decrement in number of days from planting to complete maturity and high increment dry herb weight/plant were achieved when vernalized seeds at 3° C combined with GA_3 at 100 ppm. Plants treated with GA_3 promoted flowering quality and reduction of days from planting to flowering and maturity this reduction may be due to early flowering primordial development and early cell differentiation, this may be one of the causes of early maturity [24].

The data presented in Tables 5 and 6 indicated a considerable variation in the number of umbels/plant, fruit yield/hill (g), fruit index, and fruit yield / fed. (Kg) in all vernalized seeds at a different temperature over control. Application of vernalized seeds at 3° C led to significant increase and maximum values of number of umbels/plant, fruit yield/hill (g), fruit index, and fruit yield / fed. (Kg) followed vernalized seeds at 6° C then vernalized seeds at 0° C in both season. Also, the above-mentioned parameters were significantly increased when vernalized seeds at 3° C compared to vernalized seeds at 0° C or 6° C in both seasons. The results of the present investigation are in accordance with the findings of [7] noticed that vernalized seeds of *Hibiscus sabdariffa* resulted in higher fruits/plant and improved total calyx yield as compared to control. In this regard, the application of plant growth regulator (GA_3) increased the number of umbels/plant, fruit yield/hill (g), fruit index, and fruit yield / fed. (Kg). The highest number umbels/plant and fruit index the heaviest fruit yield/hill (g) and fruit yield / fed. (Kg) were recorded from 100 ppm GA_3 treatment followed by 50 ppm GA_3 treatment and the minimum in above-stated characteristics was obtained from the control. There were significant differences between the results of fruits parameters of those plants treated with 50 or 100 ppm of GA_3 and non-treated plants, in both seasons. The results are in accordance with the findings of [4, 9 and 5] who concluded that the application of GA_3 was found effective for securing higher yield of coriander. Data also reported that there is significant effect between vernalized seeds and GA_3 on yield characters. Vernalized seeds at 3° C + GA_3 at 50 or 100 ppm recorded the highest number of umbels/plant and fruit index, the heaviest yield of fruits (per hill and fed.) with significant differences among these treatments during both seasons. According to these results and from an economic point of view it is better to vernalized seeds at 3° C and them with GA_3 at 100 ppm to gain the maximum fruit yield of coriander plants. The increases in fruits yield of coriander to vernalization and GA_3 treatments might because of the increase in vegetative growth characteristics, early flowering, fruits filling, number and weight of fruits. These results are in agreement with those of [21] who stated that seeds vernalization with 150 ppm gibberellins were increased the heads yield and reduce the time required onset of heads in cabbage.

Data presented in Table 7 indicate that, in most cases, under the three temperature of vernalized coriander seeds (0° C, 3° C and 6° C) gave significant increments were obtained volatile oil percentage and volatile oil yield (ml / plant) as compared to control during both seasons. Moreover, vernalized seeds at 3° C gave the highest coriander oil with a significant difference, when compared to other vernalization temperatures. In addition, the highest percentages of coriander essential oil (0.41 and 0.43 %) were obtained when seeds were vernalized at 3° C followed by seeds were vernalized at 6° C and 0° C (0.34 and 0.36%) in the first and second seasons, respectively. While the highest volatile oil yield per plant (0.131 and 0.147 ml/plant) was of 3° C followed by 6° C (0.109 and 0.126 ml/plant) then 0° C (0.109 and 0.119 ml/plant) in both seasons, respectively. The increment of volatile oil yield (ml/ plant) may be due to the increase of seed weight and / or volatile oil percentage. The percentage of volatile oil and oil yield (ml/plant) analysis to evaluate the effect of GA_3 on coriander active constituents are presented in Table 7. Both concentrations of GA_3 (50 and 100 ppm) promoted accumulation of volatile oil (as a percentage) with the superiority of GA_3 at 100 ppm but not enough to result in significant differences. The highest percentages of coriander essential oil (0.36 and 0.38 %) were obtained when plants treated with GA_3 at 100 ppm followed by GA_3 at 50 ppm (0.35 and 0.37%) in the first and second seasons, respectively. Volatile oil yield (ml/plant) was significantly affected by the application of GA_3 at 50 and 100 ppm while the highest volatile oil yield per plant (0.115 and 0.129 ml/plant) was of 100 ppm GA_3 (0.115 and 0.129 ml/plant) followed by 50 ppm GA_3 (0.106 and 0.120 ml/plant) in both seasons, respectively. The same conclusion was mentioned by [25 and 9]. Data in Tab. 7 reveal that seeds vernalized at 3° C and treated with GA_3 at 100 ppm produced the highest volatile oil percent (0.41 and 0.43 %) and oil yield (0.145 and 0.160 ml /plant), respectively, followed by seeds vernalized at 3° C and treated with GA_3 at 50 ppm but not enough to result in significant differences, in both seasons. There are significant differences between vernalized seeds at 3° C+ GA_3 and vernalized seeds at 0° C or 6° C + GA_3 in the above-mentioned traits. Improvement of the essential oil percentage in coriander fruits in response to GA_3 application has been reported by [4 and 10]. In this respect many authors reported that essential oil percentage varies according to cultivation practices, ontogenetic, genetic factors and environmental conditions [13, 26, 27, 28 and 29].

The main components of volatile oil of coriander seeds at different treatments were determined qualitatively and quantitively by GLC where ten main components were identified. Total identified main components ranged from 94.77 to 98.49 %. The total oxygenated compounds were the dominant compounds where they ranged from 77.25 to 85.89 % while, total hydrocarbon compounds recorded 10.84 – 19.45. The 1st major compound was linalool (68.22 – 76.71 % followed by ß-Pinene (4.51 – 8.34%). The 3rd one was α- pinene (2.74 – 6.17).

The obtained results by Gas chromatographic analysis in Table 8 pointed out that the different vernalization temperatures caused a difference in the constituents of coriander volatile oil (α-pinene, Camphene, Sabinene, ß-Pinene, P-Cymene, linalool, Geraniol, Borneol, Linalyl acetate and geranyl acetate). Vernalized seeds at 3° C gave the highest values of α-pinene, ß-Pinene and linalool compared to vernalized seeds at 0° C or 6° C. In the same table ten components of coriander volatile oil were identified and quantified for the first season samples were influenced by the application of GA_3.

The application of GA_3 at 50 or 100 ppm improved the quality of coriander essential oil by increment of the major component (linalool) percentage in the oil compared to control. Moreover, interaction of vernalized seeds at 0° C, 3° C or 6° C with application of GA_3 at 50 or 100 ppm increment the major component (linalool) of coriander volatile oil compared to control or control. At the same time, the interaction between vernalized seeds at 3° C with GA_3 at 100 ppm gave the highest values of major component (linalool) of coriander volatile oil compared to control or other ones. Similar results were found by [29] showed that GA_3 had a significant effect on linalool and camphor in sweet basil oil and recorded the highest average of these traits in comparison with control treatment.

It is clear from the above mentioned results that, the most treatments did not show a pronounced change in the main components of the volatile oil. This may be due to that these treatments had no effect on enzymatic systems responsible for the biosynthesis of these compounds.

Table 7 Effect of vernalization and gibberellic acid treatments on volatile oil % and volatile oil yield/hill (ml) of coriander plant during both seasons.

Temperature	Gibberellic acid (GA_3) concentration							
	0.0	50 ppm	100 ppm	Mean (C)	0.0	50 ppm	100 ppm	Mean (C)
	Volatile oil %				Volatile oil yield/hill (ml)			
	First season (2018/2019)							
Control	0.31	0.31	0.32	0.31	0.077	0.089	0.096	0.087
0°C	0.33	0.34	0.35	0.34	0.090	0.101	0.109	0.100
3°C	0.38	0.42	0.43	0.41	0.114	0.135	0.145	0.131
6°C	0.33	0.34	0.35	0.34	0.093	0.100	0.109	0.101
Mean(G)	0.34	0.35	0.36		0.093	0.106	0.115	
LSD at 5 %	C=0.028 G=0.024 CxG=0.047				C=0.011 G=0.009 CxG=0.017			
	Second season (2019/2020)							
Control	0.32	0.33	0.34	0.33	0.087	0.102	0.109	0.099
0°C	0.35	0.36	0.37	0.36	0.096	0.114	0.119	0.110
3°C	0.40	0.43	0.44	0.43	0.130	0.151	0.160	0.147
6°C	0.35	0.35	0.37	0.36	0.106	0.113	0.126	0.115
Mean(G)	0.35	0.37	0.38		0.105	0.120	0.129	
LSD at 5 %	C=0.037 G=0.032 CxG=0.063				C=0.015 G=0.013 CxG=0.015			

Table 8 Effect of vernalization and GA_3 treatments on relative percentage of main components of Coriander oil during first season.

Coriander oil components	Formula	Without GA_3				50 ppm GA_3				100 ppm GA_3			
		0.0	0°C	3°C	6°C	0.0	0°C	3°C	6°C	0.0	0°C	3°C	6°C
α –Pinene	$C_{10}H_{16}$	5.45	5.05	5.36	4.23	3.71	4.84	3.06	4.27	6.17	4.94	2.74	4.76
Camphene	$C_{10}H_{16}$	1.19	1.16	0.96	1.05	3.01	1.67	0.77	1.59	1.31	1.23	0.80	0.96
Sabinene	$C_{10}H_{16}$	0.62	0.63	0.40	0.66	0.65	.071	0.61	0.59	0.91	0.77	0.61	0.43
ß-Pinene	$C_{10}H_{16}$	8.14	8.07	8.34	6.34	6.77	6.87	5.95	6.32	7.79	6.44	4.51	7.10
P-Cymene	C10H16	3.38	3.31	2.64	2.16	3.62	1.36	2.19	1.77	3.27	3.34	2.18	2.37
Linalool	$C_{10}H_{18}O$	68.22	70.09	73.04	72.07	68.69	71.25	74.71	72.64	69.24	71.29	76.71	73.01
Geraniol	$C_{10}H_{18}O$	2.73	1.62	0.80	2.06	0.84	1.36	1.20	1.44	1.36	1.37	1.17	0.88
Borneol	$C_{10}H_{18}O$	4.08	4.43	3.87	4.07	4.55	4.19	4.67	3.84	4.25	3.91	4.28	4.01
Linalyl acetate	$C_{12}H_{20}O_2$	2.00	2.14	1.65	1.30	1.93	2.15	2.17	2.08	2.25	1.89	2.53	2.24
Geranyl acetate	$C_{12}H_{20}O_2$	1.17	1.19	1.43	2.40	1.24	1.01	1.51	1.63	1.01	1.09	1.20	1.30
Total identified compounds		96.98	97.69	98.49	96.34	95.01	94.771	96.84	96.17	97.56	96.27	96.73	97.06
Total hydrocarbons compounds		18.78	18.22	17.7	14.44	17.76	14.811	12.58	14.54	19.45	16.72	10.84	15.62
Total oxygenated compounds		78.2	79.47	80.79	81.9	77.25	79.96	84.26	81.63	78.11	79.55	85.89	81.44

5. Conclusion

Seed vernalization at 0° C or 6° C were less effective when compared to the treatment of 3° C for all studied characteristics. Vernalization at 3° C of coriander seeds led to greater efficiency in the plant height, number of branches per plant, number of umbels per plant, fruits yield, volatile oil percentages and volatile oil yield per plant, oil content of linalool and took minimum number of days to 50% flowering and maturity compared with other treatments (Table 8). The application GA_3 at 100 ppm was also gave the highest average in above-mentioned parameters compared to other GA_3 treatments. The interaction between vernalized at 3° C and 100 ppm of GA_3 reached the highest average in all studied characteristics especially in decrease the number of days to 50% flowering and maturity and reduction of the crop cycle.

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