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Effect of sowing date and plant density on yield and yield components of fennel (*Foeniculum vulgare*)

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Abstract

To study the effect of sowing date and plant density on yield and yield components of fennel in research field of Islamic Azad University, Birjand branch, Iran in 2009 as a split-plot experiment based on a randomized complete block design with three replications. The main plot was sowing date at three levels of March 19, April 9 and April 30 and the sub-plot was plant density at three levels of 6.7, 10 and 20 plants/m². According to the results, the effect of sowing date, plant density and their interaction was significant on umbel number per plant, seed number per umbel, 1000-seed weight and seed yield. Means comparison indicated that the highest umber number per plant, umber number per m², seed number per umbel and seed yield was obtained at the first sowing date and the delay in sowing significantly decreased them, while it increased 1000-seed weight. Also, means comparison indicated that the increase in plant density led to the significant decrease in umbel number per plant and seed number per umbel but it significantly increased umber number per m², 1000-seed weight and finally, seed yield. In total, according to the results, it is recommended to use sowing date of March 10 with the density of 20 plants/m² for the cultivation of fennel in Birjand, Iran since it produced 1163.30 kg/ha.

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Introduction

Nowadays, given the side effects of chemical medications and growing tendency to herbal medicine, mass cultivation of various medicinal herbs has been interested. The diversity of climates and ecological conditions of Iran has made it a rich country with invaluable resources of medicinal herbs and prone to cultivation of them. Fennel is an herb which has been traditionally taken the attention of researchers because of it medicinal effects. Fennel (*Foeniculum vulgare*) is an herbaceous perennial plant and is one the most important medicinal herbs in genus *Foeniculum* (Hornak, 1992) and grows at different parts of Iran as a wild plant.

Since environmental factors explicitly influence growth and development and yield of medicinal herbs (Omidbeigi, 1997), studying the effect of these factors, e.g. sowing date and plant density, on medicinal herbs is crucially important. To introduce a new crop in a region, its interaction with agronomic, genetic and climatic factors must be scrutinized (ADAS, 2002).

Sowing date is a very important parameter in crop production. The optimum sowing date paves the way for better-use of time, light, temperature, precipitation and other factors. In a study on the effects of plant density and sowing date on yield of fennel in Isfahan, Iran, Bahreininejad *et al.* (2006) fount that the sowing date of April 6 with seed yield of 2317.6 kg/ha was significantly superior over the sowing date of April 27 with that of 1612.7 kg/ha and the plants sown in May 15 encountered very high temperatures of summer on one hand and were not able to compete with thermophile weeds on the other hand and so, they were severely damaged. Zahtab Salmasi *et al.* (2003) studied the effect of three sowing date (March-May) on *Pimpinella anisum* and concluded that delayed sowing decreased plant height, harvest index, umbel number, seed number, 1000-seed weight and seed yield. In a similar study, Azizi (1998) stated mid-March as the most appropriate sowing date of *Pimpinella anisum* and noted that retarding the sowing led to 30-40% loss of yield. In a study on *Trachyspermum copticum* L., Boroomand Rezazadeh *et al.* (2005) found that the delay in sowing reduced yield.

Plant density is important with respect to better use of all production factors and inputs, too. On one hand, plant deficit per unit area prevents maximum usage of production parameters and on the other hand, excessive density can increase the competition and decrease the yield. Koocheki *et al.* (2006) studied the fennel densities of 40, 50, 60 and 100 plants/m^2 and concluded that as the density was increased from 40 to 100 plants/m^2, umbel number per plant and seed number per umbel tended to decrease, but 1000-seed weight was not affected. In addition, umbel number per m^2 and seed yield increased with plant density. However, Bahreininejad *et al.* (2006) reported that the fennel density of 3.5 plants/m^2 produced 2669.3 kg seed/ha and was significantly superior over other studied densities, i.e. 5 and 10 plants/m^2.

In a study on the effect of plant density on yield and yield components of *Pimpinella anisum*, Shareh (1999) stated that seed yield increased as the density was increased from 60 to 180 plants/m^2. Tabatabayi *et al.* (2010) studied the effect of N fertilization and plant density on *Trachyspermum copticum* L. and reported that the highest flower-bearing branch number and umbel number per plant was obtained at the density of 180 plants/m^2.

In a study on the effect of sowing date and plant density on seed yield of fennel, Darzi *et al.* (2002) showed that they significantly affected seed yield and that the best sowing date was March 25 and the best density was 10 plants/m^2. In a study on the effect of sowing date and plant density on seed yield and yield components of *Pimpinella anisum*, Rassam *et al.* (2007) concluded that the influence of sowing date, densities and their interaction was significant on most studied traits. They stated that as plant density was increased, seed yield, biological yield, plant height and 1000-seed weight rose up, but umbel number, seed number and harvest index decreased.

Overall, the highest *Pimpinella anisum* seed yield was obtained at the first sowing date (i.e. March 30) with the density of 40 plants/m² (out of the densities of 13.33, 20 and 40 plants/m²). The current study was intended to investigate the effect of sowing date and plant density on yield and morphological traits of fennel.

Materials and methods

Study side

The study was carried out in Hajiabad Research Station of Islamic Azad University, Birjand Branch, Iran (Long. 59°13´ E., Lat. 32°52´ N., Alt. 1400 m) in 2009. The soil was loam-sandy with pH of 8.6, EC of 4.57 µmho.cm^{-1} and organic carbon content of 0.25% at the depth of 0-30 cm. The average long-time minimum and maximum temperature is 4.6 and 27.5°C with average annual precipitation of 169 mm and average minimum and maximum relative humidity of 23.5 and 59.6%, respectively. The regional climate is hot and arid.

Experimental design and treatments

It was a split-plot experiment based on a randomized complete block design with nine treatments and three replications. In this study, the effects of sowing date at three levels (March 19, April 9 and April 30) as the main plot and plant densities at three levels (6.7, 10 and 20 plants/m²) as the sub-plot were examined. Each plot was 2×6 m² with four 50-cm-long planting rows. The space between plots and replications was 1 and 2 m, respectively.

Cultivation

The field had been left fallow in the previous year. The field preparation operation including tillage was carried out in early-March. According to the results of soil test, 200 kg/ha ammonium phosphate was applied to the soil before final disking. Having disinfected by fungicide carboxin thiram with the ratio of 2:1000, the seeds were dry-sown at the depth of 2 cm. The desired plant densities were created by changing the spacing between plants at the emergence of the second filiform leaf. Given the local climate and soil type, the irrigation was carried out once every 6-10 days and the weeds were removed 3-4 times at each sowing date.

To calculate yield and yield components, an area of 2 m² was harvested from each plot considering the margin effect. Then, after counting the plants and umbels, the seeds were winnowed in order to calculate their seed yield, biological yield and harvest index. A sample of 1000 seeds was randomly taken from each plot to determine 1000-seed weight by a 0.001-precision digital scale. To specify umbel number per plant, seed number per umbel and morphological traits including plant height, main branch number per plant and stem diameter, eight plants were selected from the middle of the plots and then, they were measured. By dividing counted umbel number by the number of harvested plants, umbel number per 2 m² was obtained which was then converted to umbel number per m² by dividing by 2. In addition, seed yield was divided by biological yield and multiplied by 100 to have seed harvest index in terms of percent.

Statistical analysis

At the end, the data were analyzed by statistical software MSTAT-C and the means were compared by Duncan Multiple Range Test at 5% level. The graphs were drawn by MS-Excel.

Results

Umbel number per plant

According to the results, sowing date, plant density and their interaction significantly affected umbel number per plant (Table 1). With the delay in sowing from March 19 to April 9, umbel number decreased from 16.68 to 7.43 and different sowing dates were ranked in discrete statistical groups with respect to this trait (Table 2). Also, the increase in plant density from 6.7 to 20 plants/m² decreased umbel number per plant from 15.06 to 10.51 (Table 3). The highest and lowest umbel number per plant (21.23 and 6.5 on average, respectively) was observed under the treatment of sowing date of March 19 with the density of 6.7 plants/m² and the treatment of sowing date of April 30 with the density of 20 plants/m²,

respectively (Table 4).

Umbel number per m²

As the results of analysis of variance showed, umbel number per m² was significantly affected by sowing date and plant density, but not by their interaction (Table 1). Means comparison indicated that the delay in sowing from March 19 to April 30 decreased umbel number/m² from 163.1 to 88.3 (Table 2). Umbel number/m² increased with plant density, so that as the density was increased from 6.7 to 10 and 20 plants/m², umbel number/m² increased by 23.8 and 83%, respectively (Table 3).

Table 1. Results of analysis of variance for the effect of sowing date and plant density on yield and yield components of fennel.

Sources of variation	df	Umbel number per plant	Umbel Number per m²	Seed number per umbel	1000-seed weight	Seed yield
Replication	2	18.56**	7441.002^{ns}	5364.87*	0.064^{ns}	18622.37^{ns}
Sowing date (A)	2	200.397**	16247.03*	64321.64**	1.76**	1723440**
Error *a*	4	0.664	1642.763	760.001	0.045	7309.883
Plant density (B)	2	47.338**	16865.51**	8849.96**	0.494**	178710.7**
A × B	4	8.691**	2237.644^{ns}	1276.92**	0.03*	19296.69**
Error *b*	12	0.375	1745.103	71.759	0.008	542.258
C.V. (%)	-	4.86	30.42	6.01	3.06	3.88

ns, * and ** show non-significance and significance at 5 and 1% levels, respectively.

Seed number per umbel

The results of analysis of variance indicated that the effect of sowing date and plant density on seed number per umbel was significant at 1% level (Table 1). According to the results, as sowing was retarded from March 19 to April 30, seed number per umbel decreased by 76.3%. The highest seed number per umbel (220.69 on average) was observed at sowing date of March 19 (Table 2). Means comparison showed that seed number per umbel decreased from 155.62 to 105.02 with the increase in density from 6.7 to 20 plants/m². However, there was no significant difference in seed number per umbel between the densities of 6.7 and 10 plants/m² and the highest one with the average amount of 166.41 was obtained under the density of 10 plants/m² (Table 3). The interaction between sowing date and plant density significantly affected seed number per umbel at 1% level (Table 1) and the highest seed number per umbel with the average amount of 254.70 was obtained under the treatment of sowing date of March 19 with the density of 10 plants/m² and the lowest one (42.80 seeds per umbel) was obtained under the treatment of sowing date of April 30 with the density of 20 plants/m² (Table 4).

Table 2. Means comparison yield and yield components of fennel at different levels of sowing date.

Sowing date	Umbel number per plant	Umbel number per m²	Seed number per umbel	1000-seed weight	Seed yield (kg/ha)
March 19	16.68 a	163.10 a	220.69 a	2.62 b	1019.77 a
April 9	13.70 b	160.63 a	150.03 b	2.86 b	635.63 b
April 30	7.43 c	88.30 b	52.33 c	3.48 a	146.62 c

Means with the same letter(s) in each column had no significant difference at 5% level.

1000-seed weight

The effect of sowing date, plant density and their interaction was significant on 1000-seed weight (Table 1). As means comparison indicated, although the delay in sowing adversely affected umbel number per plant, umbel number per m² and seed number per umbel, the highest 1000-seed weight (3.48 g, on average) was observed at the sowing date of April 30

which was ranked in superior group compared with

the sowing dates of April 9 and March 19. These two sowing dates were ranked in the same statistical group with respect to 1000-seed weight (Table 2). As that shown in Table 3, 1000-seed weight increased with density, so that with the increase in density from 6.7 to 10 and 20 plants/m², 1000-seed weight increased by 4.6 and 16.1%, respectively and the density of 20 plants/m² produced the highest 1000-seed weight (3.24 g, on average). In addition, means comparison of 1000-seed weight indicated that the treatment of sowing date of April 30 with the density of 10 plants/m² had the highest 1000-seed weight (3.77 g, on average) and the treatment of sowing date of March 19 with the density of 6.7 plants/m² had the lowest one (2.50 g, on average) (Table 4).

Table 3. Means comparison yield and yield components of fennel at different levels of plant density.

Density(Plant/m²)	Umbel number per plant	Umbel number per m²	Seed number per umbel	1000-seed weight	Seed yield (kg/ha)
20	10.51 c	185.36 a	105.02 b	3.24 a	726.90 a
10	12.24 b	125.37 b	162.41 a	2.92 b	626.44 b
6.7	15.06 a	101.30 b	155.62 a	2.79 c	448.63 c

Means with the same letter(s) in each column had no significant difference at 5% level.

Seed yield

Seed yield was significantly affected by sowing date, plant density and their interaction at 1% level (Table 1), so that the delay in sowing from March 19 to April 30 decreased fennel seed yield from 1019.77 to 146.62 kg/ha (Table 2). The increase in plant density significantly increased fennel seed yield, so that the highest seed yield (726.90 kg/ha, on average) was obtained at the density of 20 plants/m² which was 16 and 62% higher than that at the densities of 10 and 6.7 plants/m² (Table 3). The highest seed yield (1161.30 kg/ha) was obtained at the treatment of sowing date of March 19 with the density of 20 plants/m² and the lowest one (97.93 kg/ha) was obtained at the treatment of sowing date of April 30 with the density of 6.7 plants/m² (Fig. 1).

Table 4. Means comparison yield and yield components of fennel at different levels of sowing date and plant density interaction

Sowing date	Density (Plant/m²)	Umbel number per plant	Umbel number per m²	Seed number per umbel	1000-seed Weight (gr)
March 19	20	15.93 b	159.66 b	254.70 a	2.60 cd
	10	21.23 a	142.71 bc	241.40 a	2.50 d
	6.7	12.17 d	242.70 a	106.30 c	3.20 b
April 9	20	13.60 c	143.59 bc	174.73 b	2.80 c
	10	15.33 b	103.01 bcd	42.80 d	2.57 cd
	6.7	6.50 f	133.85 bcd	169.07 b	3.77 a
April 20	20	7.20 f	72.87 cd	57.80 d	3.37 b
	10	8.60 e	58.19 d	56.40 d	3.30 b
	6.7	12.87 cd	179.52 ab	165.97 b	2.77 cd

Means with the same letter(s) in each column had no significant difference at 5% level.

Discussion

Seed yield is the result of various characteristics which are known as yield components. These components have high correlation with seed yield and so, they are good criteria for explaining yield fluctuations. The decrease in umbel number per plant with the delay in sowing can be related to the shortening of growth period and the decrease in assimilate production which in turn, decreases plant branching potential. On the other hand, under the delayed sowing, the plants encounter high temperatures at their sensitive development stages such as flowering and then, the flowers are not inoculated whereby fertile umbel number per plant and seed number per umbel decrease. Also, Sadeghi *et al.* (2009) and Rahimian Mashadi (1992) on cumin and Zahtab Salmasi *et al.* (2003) on *Pimpinella anisum* reported the decrease in umbel number per plant and Rassam *et al.* (2007) in the study of the effect of sowing date on *Pimpinella anisum* emphasized the decrease in seed number per umbel as the result of the delay in sowing.

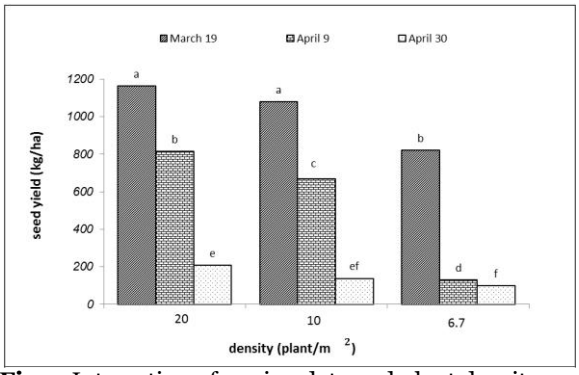

Fig. 1. Interaction of sowing date and plant density on seed yield of fennel.

Umbel number per unit area is a function of umbel number per plant and plant density per unit area. Obviously, since delayed sowing significantly decreased umbel number per plant, it decreased umbel number per unit area, too.

Means comparison of 1000-seed weight at different sowing dates indicated the 1000-seed weight was lower at delayed sowings (Table 2). Probably, the inter-plant competition over umbels as the active sinks decreased as the result of the considerable decrease in the number of reproductive units per plant and per unit area at the sowing date of April 30 (Table 2) and therefore, each seed received a greater share of the assimilates transferred to reproductive unit and seed weight increased. Also, in a study on cumin, Aminpour and Mousavi (1995) stated that as umbel number per plant increased, 1000-seed weight decreased in favor of other yield components.

In addition to shortening of growth period, coincidence with high temperature of summer during inoculation and pollination was the reason for the severe decrease in seed yield at sowing date of April 30 which severely decreased fertile umbel number per plant and seed number per umbel and finally, decreased seed yield per unit area. Also, Bahreininejad *et al.* (2006), Sharma and Prasad (1990), Hornak (1992) in their study on the effect of sowing date on fennel yield, Azizi (1998) and Zahtab Salmasi *et al.* (2003) in a study on *Pimpinella anisum*, Sadeghi *et al.* (2009) on black cumin, Kumar *et al.* (2007) on coriander, Rassam *et al.* (2006) on dill and Maletic and Jevdjovic (2007) on fenugreek reported the decrease in seed yield with the delay in sowing which is in agreement with the results of the current study.

Although the effect of density on fennel yield and yield components was milder than that of sowing date, there were significant differences in these traits. The reason for 30.2% decrease in umbel number per plant with the increase in density from 6.7 to 20 plants/m^2 (Table 3) was the increase in inter-plant competition and the shortage of space for branch-bearing and umbel-bearing of plants. In a study on the effect of density on umbel number per plant in *Pimpinella anisum*, Rassam *et al.* (2007) found similar results. Also, in a study on the effect of plant density and N fertilization on coriander, Kumar *et al.* (2007) showed that umbel number per plant significantly decreased with the increase in plant density.

Perhaps, seed number per umbel decreased at higher densities because of poor pollination and sterility of flowers due to shading at flowering stage which

decreased inoculated flowers. With the increase in density, in addition to the sterility of flowers, the stunt of the growth of inoculated embryos might decrease the number of fertile seeds. On the other hand, given the competition over light and nutrient intake, plants spend more energy and photosynthesis capacity for increasing the height through increasing internode length which in turn, decreases assimilate supply for physiological sinks of umbel and the abortion of embryos and then, the number of fertilize seeds per umbel decreases. Whereas, the partial increase in seed number per umbel under lower densities can be related to lower inter-plant competition which increases the number of fertile flowers and makes the building of more assimilates possible by uniform distribution of light which are allocated to seeds.

With the increase in plant number per unit area, umbel number per m^2 increased despite the decrease in umbel number per plant (Table 3). It can be associated with the dependence of umbel number per unit area to plant density. In other words, as plant density was increased from 6.7 to 20 plants/m^2, the 83% increase in umbel number/m^2 was able to compensate the 30.2% decrease in umbel number per plant and this was why the potential of produced the maximum umbels/m^2 was realized.

According to the results, the increase in plant density increased 1000-seed weight (Table 3). The partial decrease in 1000-seed weight under lower densities was associated with the increase in seed number per umbel. That is, it can be concluded that higher umbel number and seed number per plant at lower densities provoked inter-plant competition over assimilates which led to the loss of 1000-seed weight in favor of other yield components. Although Rassam *et al.* (2007) in the study of *Pimpinella anisum)*, Moosazadeh (2008), Ghosh *et al.* (1981) and Toncer and Kizil (2004) in the study of black cumin reported that density had no significant effect on 1000-seed weight, Sayyari (2010) in the study of marigold and Sharma (2000) in the study of fenugreek concluded that 1000-seed weight increased with the increase in plant density.

The increase in plant density had positive effect on fennel seed yield (Table 3). Under the conditions of the current study, the increase in plant density decreased umbel number per plant and seed number per umbel, but the increase in umbel number per unit area and 1000-seed weight compensated the decrease in yield per plant. In other words, it can be said that although single-plant yield increased at lower densities, the increase could not compensate the decrease in plant number; thus, yield per unit area decreased. At very low densities, environmental resources, especially radiation, is not usually well used because of low leaf area index and the delay in full plant coverage of land and then, total yield decreases.

Some researchers stated that the increase in density increased competition capability of fennel against weeds and so, in addition to the increase in radiation use efficiency with the increase in umbel number per unit area, seed yield increased (Damato *et al.*, 1994). The studies of Bahreininejad *et al.* (2006) and Koocheki *et al.* (2006) on fennel, Shareh (1999) and Rassam *et al.* (2007) on *Pimpinella anisum*, Ebdali Mashadi and Fahti (2003) on *Silybum marianum* and Tabatabayi *et al.* (2010) on *Trachyspermum copticum* L. showed the increase in seed yield with the increase in plant density, too. Also, Gowda *et al.* (2006), Derogar *et al.* (2014), Shamsi *et al.* (2014), Dashti Nejad *et al.* (2014) and Singh *et al.* (2005) stated that yield decreased under low densities because of less assimilates production.

Conclusion

In total, given the results of the study, early sowing of fennel in mid-March can be recommended for the cultivation of fennel in Birjand, Iran because plants have longer growth period duration, their growth and development coincides with favorable environmental conditions, they produce stronger vegetative parts and more assimilates. Also, higher plant density (at least 20 plants/m^2) can be recommended because of

the increase in usage of radiation and other inputs for the production of more reproductive parts per unit area.

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