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Response of different drip irrigation and fertigation levels on quality and seed yield in fennel (*Foeniculum vulgare*)

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ABSTRACT

The present experiment was conducted during winter (*rabi)* seasons of 2021–22 and 2022–23 at Chaudhary Charan Singh Haryana Agriculture University, Hisar, Haryana to study the effect of different drip irrigation and fertigation levels on quality and seed yield in fennel (*Foeniculum vulgare* Mill.) crop. The experiment was laid out in a split-split plot design in which 2 fennel varieties, viz. HF-143 and Hisar Swarup were grown with 4 levels of different irrigation scheduling, viz. I_1, 0.6 IW/CPE (Irrigation water/Cumulative pan evapo-transpiration); I_2, 0.8 IW/CPE; I_3, 1.0 IW/CPE and I_4, 1.2 IW/CPE as main plot treatments and 3 different nitrogen levels i.e. N_1, 20 kg/ha; N_2, 35 kg/ha and N_3, 50 kg/ha as sub-sub plots treatment. A range of nitrogen levels was applied in the experimental field through drip irrigation. It was clear from the study that irrigation scheduled at 1.2 IW/CPE resulted significantly higher values when irrigated for quality parameters (test weight, seed germination and vigour indices I and II) and seed yield, which was statically at par with 1.0 IW/CPE. Maximum seed yield (15.5 g/plant), test weight (5.0 g), seed germination (84.0%) and vigour indices I (1,518.98) and II (281.13) were significantly recorded at nitrogen levels 50 kg/ha. Higher seed's yield and quality parameters were recoded in variety HF-143 than Hisar Swarup. Based on the current study, it can be concluded that in the western region of Haryana, fennel variety HF-143 obtains better results, both in terms of quality and yield parameters when grown at irrigation scheduling IW/CPE 1.0 with 50 kg/ha of nitrogen level.

Keywords: *Foeniculum vulgare* (Mill.), Irrigation scheduling, Nitrogen fertigation, Seed quality

Fennel (*Foeniculum vulgare* Mill.) which is commonly known as 'saunf', is a member of Apiaceae family (Sharma and Kumar 2022). It originated in the southern Mediterranean region and due to naturalization and cultivation; it grows worldwide throughout the eastern, western and northern hemispheres, specifically in Europe, Asia and North America. India is renowned as the "Home of Spices" because it is the largest producer, consumer, and exporter of spices in all over the world (Meena *et al.* 2016). Fennel is grown mostly for its seeds, which have an aromatic flavour and pleasing fragrance.

Effective irrigation techniques like drip irrigation are needed to increase crop productivity of fennel crop to withstand growing water shortage and the requirement to yield more food per drop of water. In areas with plentiful and consistent supply of water resources throughout the growing season, it is possible to apply water as and when it is needed for crops to achieve the maximum yields (Devi *et al.* 2023). On the other hand, low crop outputs were recorded due to inadequate irrigation facilities. As a result, numerous researchers have demonstrated that drip irrigation is preferable over traditional irrigation techniques in terms of preserving water, increasing output and providing additional advantages (Meena *et al.* 2017).

One of the most important production factors in growth of fennel crop is nitrogen (N_2) fertilization, as unbalanced usage of nitrogen can significantly reduce the yield and quality of seeds as well as soil health can be greatly compromised (Angeli *et al.* 2016). Therefore, an appropriate amount of irrigation and application of fertilizer, enhances both the quality as well as the quantity of the crop. (Almedia *et al.* 2015). The process of applying fertilizer to crops through an irrigation system is known as fertigation. The right amount of irrigation and fertilizer application not only enhances yield but also enhances quality while reducing the production costs, which is exactly needs to be done today. However, very little attention has been given to studying the nutritional as well as water requirements of fennel in Haryana. Thus, the present study was designed to study the effect of different irrigation and nitrogen fertigation on fennel.

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MATERIALS AND METHODS

The present experiment was conducted during winter (*rabi)* seasons of 2021–22 and 2022–23 at Chaudhary Charan Singh Haryana Agriculture University, Hisar (29º10''N 75º 46''E), Haryana. Two fennel varieties i.e. Hisar Swarup and HF-143 were selected for the experiment and seeds were procured from the Chaudhary Charan Singh Haryana Agriculture University, Hisar, Haryana. Four levels of different irrigation scheduling i.e. I_1, 0.6 IW/CPE (Irrigation water/Cumulative pan evapo-transpiration); I_2, 0.8 IW/CPE; I_3, 1.0 IW/CPE; and I_4, 1.2 IW/CPE were taken as main plot treatments and three different nitrogen levels i.e. N_1, 20 kg/ha; N_2, 35 kg/ha; and N_3, 50 kg/ha were assessed in sub-plot treatment. During the experiment, nitrogen was applied through drip fertigation. During field preparation, a basal dosage of one half dose of nitrogen (urea) and one full dose of phosphorus (SSP) was applied based on the treatments. Three splits of the remaining half-dose of nitrogen were administered (30 days after sowing and then at 15-day intervals). Pre-sowing irrigation (40 mm) was given prior to field preparation to improve seed germination. The split-split plot design was employed and the experimental data were statistically analysed using Panse and Sukhatme (1985) analysis of variance (ANOVA) techniques. Observations were recorded on seed quality and seed yield parameters including test weight (g), seed germination (%), vigour index-I and II of fennel. Data analysis was done with help of OPSTAT software (Sheoran *et al.* 1998).

Quality parameters

Test weight (g): 1000-seeds were tallied without differentiation of their size and shape, from the seed sample taken from each plot and weighted to determine the test weight in grams.

Standard germination (%) as per ISTA (2011): The germination paper method produced standard germination. In each replication, 50 seedlings from each treatment were positioned in between the germination paper and then kept in the germinator at a temperature of 25±1°C and relative humidity of 90–95%. On the 7th day, the first record was achieved, and on the 21st day, the final count was obtained. The results obtained from the seed germination observations were expressed as a percentage (%) of seed germination.

Vigour indices: The vigour indices of seedling were calculated as per the method suggested by Abdul-Baki and Anderson (1973):

Vigour index-I (on the seedling length basis) =

Standard germination (%) × Average total seedling length (cm)

Vigour Index–II (on the seedling dry weight basis) =

Standard germination (%) × Average seedling dry weight (mg)

Yield parameter

Seed yield (g/plant): All the umbels from 10 selected plants of every treatment were harvested, dried under shade and threshed. The average weight of cleansed seeds from 5 plants was recorded as seed yield per plant in grams.

RESULTS AND DISCUSSION

Test weight: The study's findings showed that fennel treated with 1.2 IW/CPE irrigation had the highest test weight (5.1 g), which was statistically at par with 1.0 IW/CPE irrigation (5.1 g) (Table 1). The test weight, increased significantly by 19.6% under 1.2 IW/CPE over 0.6 IW/CPE irrigation scheduling. The current findings were practically identical with the results by Godara *et al.* (2013) that under ideal irrigating conditions, plant roots absorb more water. Therefore, the plant maintained its higher stomatal conductivity and leaf water potential.

Likewise, due to the effect of different nitrogen levels, significantly higher test weight (5.0 g) was resulted in fennel treated with nitrogen at 50 kg/ha over 20 kg/ha. With the application of nitrogen at different levels the test weight significantly increased by 14.0% at 50 kg/ha nitrogen level over 20 kg/ha. This could be ascribed to an enhanced nutrient's availability into the plant, which increased the amount of carbohydrates produced and transitioned them to the fennel crop (Meena *et al.* 2016, Meena *et al.* 2017, Singh *et al.* 2017). For both varieties, significantly higher test weight of fennel was recorded in HF-143 (5.2 g) over Hisar Swarup (4.1 g), which was observed significantly higher by 21.1%. The variation in quality parameters in cultivar of fennel may be due to their genetic makeup,

Table 1 Effect of irrigation levels and nitrogen fertigation on test weight, standard germination, vigour index-I and II and seed yield of two different fennel varieties

Treatment	Test weight (g)	Standard germination (%)	Vigour index-I	Vigour index-II	Seed yield (g/plant)
Variety					
V_1	4.1	81.3	1,357.08	238.53	14
V_2	5.2	81.8	1,481.58	260.16	16.5
CD (*P*=0.05)	0.044	0.061	29.44	0.68	0.2
Irrigation scheduling					
I_1	4.1	77.6	1,248.52	191.73	11.8
I_2	4.3	78.8	1,315.77	213.16	14.6
I_3	5.1	84.1	1,534.59	291.68	17.3
I_4	5.1	85.8	1,578.43	300.79	17.4
CD (*P*=0.05)	0.01	0.204	16.25	1.6	0.2
Nitrogen level					
N_1	4.3	79.2	1,330.27	222.23	15
N_2	4.7	81.5	1,408.73	244.66	15.3
N_3	5	84	1,518.98	281.13	15.5
CD (*P*=0.05)	0.003	0.163	6.19	0.63	0.1

I_1, Irrigation at 0.6 IW/CPE; I_2, Irrigation at 0.8 IW/CPE; I_3, Irrigation at 1.0 IW/CPE; I_4, Irrigation at 1.2 IW/CPE through drip; N_1, Nitrogen @20 kg/ha; N_2, Nitrogen @35 kg/ha; N_3, Nitrogen @50 kg/ha; V_1, Hisar Swarup; V_2, HF-143.

which were practically identical with the results obtained by Singh *et al.* (2017).

Standard germination: The data related to standard germination clearly revealed that in different irrigation levels, significantly maximum standard germination was recorded (85.8%) in fennel with the irrigation level at 1.2 IW/CPE (Table 1). The standard germination increased significantly by 9.6% under 1.2 IW/CPE over 0.6 IW/CPE irrigation schedule. The present study was practically identical with the results obtained by Vadar *et al.* (2016) that the stomatal opening for longer period results in higher carbohydrates production and its translocation to fruits of fennel crop. As a result, the fennel seeds excelled in every quality attribute.

With respect to different nitrogen levels, significantly higher standard germination i.e. 84.0% was resulted in fennel when treated with nitrogen level at 50 kg/ha over 20 kg/ha (79.2%), respectively. Owing to the effect of nitrogen at different levels, the standard germination increased by 5.7% at 50 kg/ha nitrogen level over 20 kg/ha. This could be in response to increased level of nitrogen distribution to the plant, which has resulted in enhancement of carbohydrate production and translocation to the fennel fruits which was also studied by Bhunia *et al.* (2009) and Ehsanipour *et al.* (2012).

Among both varieties, higher standard germination of fennel was recorded in HF-143 (81.8%) over Hisar Swarup (81.3%). It was observed significantly 4.0% higher in HF-143 over Hisar Swarup. The genetic composition of fennel cultivars may be the cause of the variance in quality criteria. The present study was practically identical with the results obtained by Singh *et al.* (2017).

Vigour index-I: Among irrigation levels, fennel treated with 1.2 IW/CPE irrigation achieved a significantly higher (1,578.43) vigour index-I (Table 1). The significant increase in vigour index-I by 20.9% under irrigation schedule of 1.2 IW/CPE over other (0.6 IW/CPE) may be due to more water absorption by plant roots at an optimum irrigation level which were practically identical with the results obtained by Meena *et al.* (2016).

In different nitrogen levels, significantly higher (1,518.98) vigour index-I was observed in fennel when treated with nitrogen at 50 kg/ha over 20 kg/ha which was increased by 12%. This could be attributed by increased supply of the nutrients to the plant, which resulted in increased availability of carbohydrates and their translocation to fennel. The improvement in quality parameters was practically identical with the results obtained by Godara *et al.* (2013), Meena *et al.* (2016).

Among both varieties, significantly higher vigour index-I of fennel was recorded in HF-143 (1,481.58) over Hisar Swarup (1,357.08). The variation in quality parameters in cultivar of fennel may be due to their genetic makeup (Singh *et al.* 2017).

Vigour index-II: The data related to vigour index-II (Table 1) clearly revealed that among irrigation levels, significantly higher vigour index-II (300.79) was resulted in fennel at 1.2 IW/CPE irrigation level, whereas, the lowest (191.73) was recorded in fennel crop treated irrigation at 0.6 IW/CPE. The vigour index-II increased significantly by 36.2% under irrigation schedule of 1.2 IW/CPE other (0.6 IW/CPE). This might be as a result of plant roots at the ideal irrigation level absorbing more water; consequently, the plant conserved a higher leaf water potential and enhanced stomatal conductance. The prolonged opening of stomata led to an increase in carbohydrate production and their translocation to fennel fruit. Likewise, results were similarly documented by Meena *et al.* (2017) and Kanwar *et al.* (2018).

With respect to different nitrogen levels, significantly higher vigour index-II (281.13) was observed in fennel treated with nitrogen at 50 kg/ha. There was a significant increase in vigour index-II by 20.9% at 50 kg/ha nitrogen level over 20 kg/ha. This could be attributed by increased supply of the nutrients to the plant, which resulted in increased availability of carbohydrates and their translocation to fennel. The enhanced quality parameters were also practically resulted by Godara *et al.* (2013), Meena *et al.* (2016) and Meena *et al.* (2017).

Among varieties, significantly higher vigour index-II of fennel was recorded in HF-143 (260.16) over Hisar Swarup (238.53), which was significantly higher by 8.3% in HF-143 over Hisar Swarup. The variation in quality parameters in cultivar of fennel may be due to their genetic makeup. The current findings closely matched with the outcomes attained by Singh *et al.* (2017).

Seed yield (g/plant): The data on seed yield revealed that among irrigation levels, fennel irrigated with 1.2 IW/CPE had a significantly higher seed production (17.4 g/plant), which was statistically at par with fennel irrigated with level 1.0 IW/CPE (17.3 g/plant) (Table 1). Our study unveiled a notable increase of 32.2% seed yield (g/plant) through 1.2 IW/CPE over 0.6 IW/CPE irrigation scheduling when analysed for both the years, which was practically related to the findings of Rao *et al*. (2010) and Harisha *et al.* (2019). Their study revealed that optimal moisture state in the crop's complete root zone manifests in improved physiologic activities of plant plants.

When overcoming moisture stress throughout the growth season, the use of an optimal amount of irrigation water maintains correct soil moisture, resulting in improved production. The effect of nitrogen level resulted in significantly higher seed yield of fennel. It was recorded maximum (15.5 g/plant) at 50 kg/ha nitrogen. Similarly, while comparing the effect of nitrogen levels the seed yield/ plant significantly increased by 3.2% at 50 kg/ha over 20 kg/ha. This may be the result of applying enough fertilizer by drip fertigation to meet the crop's nutritional needs at different phases of growth, which would have enhanced both yield and growth. Likewise, the findings were similarly documented by Ehsanipour *et al.* (2012), El-Mekawy (2012), Godara *et al.* (2013) and Harisha *et al.* (2019).

Among both the varieties, significantly maximum seed yield of fennel was observed in HF-143 (16.5 g/plant) and

Table 2 Interaction effect of irrigation levels and nitrogen fertigation on seed yield (g/plant) of two different fennel varieties

Nitrogen levels	Variety × Irrigation × Nitrogen							
	Varieties							
	V_1, Hisar Swarup				V_2, HF-143			
	Irrigation levels							
	I_1	I_2	I_3	I_4		I_1	I_2	I_3	I_4
N_1	9.6	13.4	15.9	16.0	N_1	12.8	15.4	18.3	18.3
N_2	10.7	13.5	15.9	16.2	N_2	13.1	15.7	18.5	18.6
N_3	11.1	13.6	16.3	16.3	N_3	13.4	16.1	18.7	18.8

Varieties	Variety × Irrigation					Varieties	Variety × Nitrogen			
	Irrigation levels						Nitrogen levels			
	I_1	I_2	I_3	I_4	Mean V		N_1	N_2	N_3	Mean V
V_1	10.5	13.5	16.0	16.2	14.0	V_1	13.7	14.1	14.3	14.0
V_2	13.1	15.7	18.5	18.6	16.5	V_2	16.2	16.5	16.8	16.5
Mean I	11.8	14.6	17.3	17.4		Mean N	15.0	15.3	15.5	

Irrigation level	Irrigation × Nitrogen				CD at 5% level of significance	
	Nitrogen level				Variety	0.2
	N_1	N_2	N_3	Mean I	Irrigation	0.2
I_1	11.2	11.9	12.3	11.8	Nitrogen	0.1
I_2	14.4	14.6	14.8	14.6	Variety × Irrigation	NS
I_3	17.1	17.2	17.5	17.3	Variety × Nitrogen	NS
I_4	17.1	17.4	17.6	17.4	Irrigation × Nitrogen	0.1
Mean N	15.0	15.3	15.5		Variety × Irrigation × Nitrogen	0.2

I_1, Irrigation at 0.6 IW/CPE; I_2, Irrigation at 0.8 IW/CPE; I_3, Irrigation at 1.0 IW/CPE; I_4, Irrigation at 1.2 IW/CPE through drip. N_1, Nitrogen @20 kg/ha; N_2, Nitrogen @35 kg/ha; N_3, Nitrogen @50 kg/ha.

minimum was obtained with Hisar Swarup (14.0 g/plant). There was significantly 14.9% increase in seed yield/plant in HF-143 over Hisar Swarup. This is one to fact that variety HF-143 had bolder seed as compare to other variety. Likewise, results were also stated by Bhunia *et al.* (2009).

Interaction effect of the different irrigation and nitrogen fertigation on seed yield (g/plant): The interaction effect among different irrigation and nitrogen levels (I×N) demonstrated that significantly maximum seed yield (17.6 g/ha) was recorded in fennel crop sown at the 1.2 IW/CPE irrigation level combined with 50 kg/ha (I_4N_3) applied dose of nitrogen (Table 2), which was statistically at par when fennel sown at 1.0 IW/CPE irrigation level with 50 kg/ha nitrogen dose (17.5 g/ha).

The interaction effect of both varieties, different fertilizer and irrigation levels (V×I×N) on seed yield (g/plant) revealed that significantly higher seed yield (18.8 g/plant) was recorded in the variety HF-143 which was sown at irrigation level of 1.2 IW/CPE with the nitrogen at 50 kg/ha ($V_2I_4N_3$), and was statistically at par with the irrigation level of 1.2 IW/CPE with nitrogen at 35 kg/ha (18.6 g/plant) and irrigation level of 1.0 IW/CPE with nitrogen dose at 50 g/ha (18.7 g/plant), respectively.

While comparing the interaction effect of different irrigation scheduling with nitrogen levels, seed yield g/plant significantly increased by 49.0% at irrigation scheduled at 1.2 IW/CPE with 50 kg/ha of nitrogen level over the combination of irrigation scheduled at 0.6 IW/CPE with 20 kg/ha nitrogen level. The increased yield could be attributed by improved water utilization and nutrient uptake, as well as an outstanding soil-water connection in the root zone. Likewise, results were similarly documented by Hebbar *et al*. (2005), Aujla *et al.* (2007), Savitha *et al.* (2010) and Ningaraju and Joseph (2014).

Based on the 2-years experiment, it can be concluded that seed quality and seed yield of fennel crop were found superior when irrigation scheduling at 1.0 IW/CPE was given with the combination of 50 kg/ha of nitrogen level. Variety HF-143 was found suitable with respect to seed quality and seed yield with in the western region of the Haryana state during 2021–22 and 2022–23, respectively.

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