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Effect of plant density and foliar nutrient application on seed yield and quality in Asiatic carrot (*Daucus carota*)

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ABSTRACT

A field experiment was conducted to study effect of plant density and foliar spray of nutrients on carrot (*Daucus carota* L.) seed yield and quality during winter season of 2012-13 and 2013-14. Plant height, days to 50% flowering, number of umbels/plant, number of seeds/umbel, seed yield/umbel, percentage contribution of different order umbel to total seed yield, seed yield/plant, seed yield/ha, 1 000 seed (mericarp) weight, germination (%) and vigour index were recorded. Significant highest average plant height, earliness in days to 50% flowering and seed yield/ha (12.9 q) were observed in high plant density (13 plants/m^2). More number of secondary (11.6) and tertiary umbels (30.1) and higher seed yield/plant (25.2g) were recorded in low plant density (4 plants/m^2). Per cent contribution of primary umbel to total seed yield was maximum (41.76%) in 13 plants/m^2 and minimum (16.89%) in 4 plants/m^2. But an increasing trend in contribution percentage to total seed yield by secondary and tertiary umbels was recorded from 13plants/$m^2$to 4plants/m^2.Seeds from primary and secondary umbels recorded high quality in plant density of 5 plants/m^2 and 4 plants/m^2 respectively.Comparative reduction in pooled seed vigour was observed in 7 plants/m^2 and 13 plants/m^2. Foliar spray of 0.1% $MgSO_4$at 30 and 60 days after transplanting (DAT) increase the seed quality. Both seed yield and qualityincrease was observed in 0.1% borax spray at 30 and 60 DAT.

Key words: Borax, Carrot, Foliar nutrient spray, $MgSO_4$, Plant density, Seed quality, Seed yield

Carrot (*Daucus carota* L.) is one of the important root vegetable in umbelliferae family. It covers an area of 62.4 thousand ha in India with the production of 10.7 lakh tonnes (Saxena and Gandhi 2015). Both Asiatic and temperate type carrots are cultivated in India but they require different climatic condition for their seed production. Seeds of Asiatic type can be produced in plains but that of temperate types in hilly region only. Carrot inflorescence consistsof many branches and is divided into different order umbels (primary, secondary and tertiary etc.) based on their position and developmental stages. This also leads to production of seeds in different maturity levels. When the primary umbel reaches maturity the secondary or tertiary umbels may be in immature or flowering stage, respectively. This is one of major problem in seed production of carrot crop. Highest contribution by primary umbel to total seed yield in high density planting in temperate carrot was demonstrated (10 to 80 plants/m^2, 2-84 plants/$m^2$and 2-100 plants/m^2) by many authors (Gray *et al*. 1983, Gray and Steckel 1983 and Merfield *et al*. 2010). High quality seeds are generally produced from primary and secondary umbels in carrot (Pandita *et al.* 2005). This indicates promotion of primary and secondary umbel by increasing plant density may promote uniform maturity and quality of seeds. But there is a need of fine balance between increase in plant density, increase in seed yield and maintenance of seed quality. One should not compromise seed quality for higher seed yield by increasing plant density. The optimum plant density also depends upon environment and cultivars. Apart from plant density, balanced nutrition of macro and micronutrients also play a vital role in increase and enhancement of seed yield and quality. In this study an attempt was made to suppress the side branches of inflorescence by increasing the plant density in carrot and to know the supportive effect off oliar nutrient for obtaining higher seed yield and quality in carrot.

MATERIALS AND METHODS

The experiment was conducted at Seed Production Unit of Indian Agricultural Research Institute, New Delhi during the period of September to May, 2012-13 and 2013-14. The experimental site was situated at 28°35'N latitude & 77°12'E longitude and at an altitude of 228.6 m above mean sea level. Seeds of carrot cv. Pusa Rudhira were sown in the last week of September and transplanting of uniform size steckling was done in third

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week of January. Split plot design was adopted to conduct experiments with plant density as main plot treatment and foliar spray of nutrients as sub-plot treatments. Stecklings were transplanted with spacing of 15×50cm, 30×50cm, 40×50cm and 50×50cm which gave plant density of D_1-13 plants/m^2, D_2-7 plants/m^2, D_3-5 plants/m^{2}and D_4-4 plants/m^2 respectively. Sub-plot size was 3m×3m and main plot consists of seven sub-plots for six foliar spray treatments and one control. Main plots were replicated three times with all sub-plot treatments. Foliar spray treatments consist of T_1-0.1% borax at 30 DAT, T_2- 0.1% borax at 60 DAT, T_3- 0.1% borax at 30+60 DAT, T_4- 0.1% Magnesium sulphate ($MgSO_4$) at 30 DAT, T_5- 0.1% $MgSO_4$ at 60 DAT, T_6- 0.1% $MgSo_4$ at 30+60 DAT and T_7- control (sprayed with water). Borax used as boron source. All the package of practices and plant protection measures were carried out as per recommendation. Days to 50% of flowering was counted from initiation of primary umbel to 50% flowering of primary, secondary and tertiary umbels in individual treatment. Plant height of 10 randomly selected plants was measured at the time of 50% of flowering. Number of umbels/plant, percentage contribution of all different order umbel(s) to total seed yield and seed yield/plant was estimated from average of observations taken from ten randomly selected plants at the time of harvest. Number of seeds/umbel and seed yield/umbel was estimated from 10 randomly selected umbels of different order. Seed yield/ha was estimated based on average of main plot and subplot seed yield. Seed quality parameters like 1 000 seed weight, germination percentage (ISTA 2012) and vigour index (Abdul-Baki and Anderson, 1973) were calculated. Since seeds of primary and secondary umbels were combined together in general seed lot, a pooled vigour index was also calculated by taking average of seed vigour index one of primary and secondary umbels. Statistical analysis was carried out by a software AgRes version 3.01.

RESULTS AND DISCUSSION

Growth attributes

In the present study higher average plant height with respect to primary (118.7cm), secondary (133.6cm) and tertiary (139.4cm) umbels were observed in highest plant density (D_1). This may be due to more apical growth and suppression of side branches. Similar results have also been reported by Ahmad and Tanki (1997) and Kumar (2005) in carrot. In case of other crops, increasing plant density generally reduces the plant height or length due to competition among plants for space, nutrient and sunlight. Bahlgerdi *et al*. (2014) observed highest plant length in medicinal pumpkin in lowest plant density. Highest plant density (D_1) recorded earliness for days to 50% flowering as compared to other plant densities. Decreasing plant density showed delay in days to 50% flowering. Earliness in flowering may be due to competition between plants in D_1. Andriolo (1999) reported that an optimized leaf area index (LAI) can be obtained by ideal population density for better interception of maximum useful radiation for photosynthesis. Before plants start the reproductive phase, an optimized LAI can be reached very early on high density

Table 1 Effect of plant density and foliar spray on growth and flowering in carrot cv. Pusa Rudhira (Pooled data of two season 2012-13 and 2013-14)

Treatment	Plant height (cm)			Days to 50 % flowering			Number of umbels/plant	
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Secondary	Tertiary
plant density								
D_1	118.7^a	133.6^a	139.4^a	26.5^c	33.3^d	40.2^c	6.2^d	17.5^d
D_2	112.7^b	127.7^b	131.5^b	27.3^b	34.1^c	41.5^b	9.3^c	23.8^c
D_3	108.9^b	123.6^c	126.6^c	27.8^{ab}	34.5^b	43.0^a	11.3^b	27.5^b
D_4	104.1^c	121.5^c	124.5^c	28.3^a	35.0^a	43.4^a	11.6^a	30.1^a
CD (P=0.05)	3.96	2.97	3.96	0.60	0.34	1.02	0.12	1.10
Foliar nutrient spray								
T_1	110.0	126.1	129.4	27.1	33.8	41.5	9.6	24.6
T_2	112.0	127.5	130.6	27.5	34.1	42.0	9.7	25.1
T_3	113.3	128.6	131.5	27.8	34.6	42.4	9.7	25.7
T_4	110.4	125.1	130.2	27.1	34.0	41.5	9.5	24.0
T_5	110.9	126.8	130.9	27.6	34.1	42.0	9.6	24.6
T_6	111.8	128.1	131.8	28.1	34.8	42.9	9.6	25.3
T_7	109.2	123.9	129.1	27.1	33.8	41.8	9.5	23.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
D×T	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters are statistically different. Separation done by Duncan's Multiple Range Test.

plantings. Thus, planting density in any crop influences plant growth, changing the flower initiation and fruit development and interfering on the biomass distribution between source and sink.Number of umbels/plant increased with decrease in plant density and was highest in D_4 for both secondary (11.6) and tertiary umbels (30.1). This may be due to availability of more nutrient and sunlight to individual plants in low plant density. These results are in accordance with Kumar (2005) in carrot. None of the growth parameters were recorded significant difference with respect of foliar nutrient sprays. No significant interaction effect was observed between density and foliar nutrient spray for all growth attributes (Table 1).

Seed yield attributes

Highest number of seeds/primary umbel was observed in D_2 (1742) and D_3(1725) followed by D_1(1700) and D_4(1702). This indicates both reduction and increase in plant density affect the seed number in primary umbel. Lowest plant density (D_4) recorded highest number of seeds in secondary and tertiary umbel. Similar results were observed in onion by Asaduzzaman *et al.,* (2012). Seed yield/primary umbel was recorded higher and on par in D_2 (4.24g), D_3 (4.30g) and D_4 (4.22g) than D_1(4.03). Seed yield/secondary and tertiary umbels were highest in lowest plant density (D_4).

Percentage contribution by primary umbel (41.73%) to total seed yield was observed highest in high plant density (D_1). But D_3 and D_4 received significantly highest contribution from secondary umbels because increased number of secondary umbel in low plant density. Contribution of tertiary umbels to total seed yield (10.70%) was highest in lowest plant density (D_4). None of the foliar spray recorded significant differences with respect to percentage contribution in primary and secondary umbels. Seed yield/plant was highest (25.2g) in lowest plant density (D_4). But seed yield/ha was significantly higher (12.9q) in highest plant density (D_1). It may be due to increased plant population in high plant density (D_1).These results are similar with results obtained by Guerrero *et al*. (1986), Amjad and Anjum (2001), Lima *et al*. (2003)and Pandita *et al*. (2005) in temperate and tropical carrot cultivars.

Recent studies in watermelon (Edelstein and Nerson 2002), muskmelon (Nerson 2002), onion (Kanwar *et al*. 2000) and medicinal pumpkin (Bahlgerdi *et al*. 2014) showed that relatively high plant densities were required to obtain the highest seed yield. In contrary, there are few reports in seed production of winter squash and squash suggested low plant densities for higher seed yield (Dematte *et al*. 1978, Edelstein *et al*. 1985, Lima *et al*. 2003). Al Mamun *et al*., (2016) also reported that early planting of potato top shoot cutting with closer spacing (50×10 cm and 50×15cm) was most suitable for breeder seed multiplication. So optimization of plant density for seed production of any crop and their different cultivars are very important to obtain higher seed yield and seed quality.

Among the foliar sprays, T_3 recorded higher number of seeds, seed yield/umbel, seed yield/plant (20g) and seed yield/ha (12.3q). However, $T_6$was on par for number of seeds and seed yield/primary umbel with T_3. These results are in accordance with results obtained by Sharma *et al.* (1999), Vrataric *et al*. (2006) and Kumar *et al.,* (2012). For all seed yield attribute, significant interaction between density and foliar spray was not observed (Table 2).

Seed quality attributes

Highest 1 000 seed (mericarp) weight with respect to primary umbel was recorded in D_3 (2.489g) followed by D_2 (2.446g) and D_4 (2.476g). Many authors reported highest 1 000 seed weight of carrot in less plant density (Kumar 2005). In our study maximum seed weight was observed in D_3 instead of D_4. Higher number secondary and tertiary umbel in D_4 leads to slight quality reduction in seeds form primary umbel. Though, only primary umbels promoted in D_1, the reduced seed weight indicate the competition among the plants for various resources.

Similar kind of results was observed in *Cucurbita pepo*. L (Loy 1988) and medicinal pumpkin (Bahlgerdi *et al.* 2014). These results indicated requirement of optimum level of plant density for quality seed production instead of high or less plant density. Plant density had no significant effect on germination per cent of seeds from primary umbels. Seeds of secondary and tertiary umbels recorded highest germination at lowest plant density (D_4). Highest significant vigour index with respect to primary umbel was recorded in D_3 (1134) followed by D_2 (1077) and D_4 (1087). An increasing trend of vigour index was observed for seeds of secondary and tertiary umbel from highest (D_1) to lowest plant density (D_4). Foliar spray treatment T_3(2.472g) had maximum test weightfrom primary umbels and was on par with T_2 (2.457g) and T_6 (2.458g), 1 000 seed weight was observed highest with T_3 in secondary and tertiary umbel. Similar results were also observed in chilli (Dongre *et al.* 2000) and Niger (Paikray, *et al.,* 2001).

Among the foliar treatments, both T_3 and T_6 recorded significantly highest germination percentagein seeds from primary, secondary and tertiary umbel. T_3 followed by T_6 recorded highest vigour index for seeds of all order umbels. The following may be the reason for seed quality enhancement by T_6. Magnesium is central element in chlorophyll. It participates in activity of many enzymes and involved in phosphorous translocation (Curley 1994). Foliar ‘boosting’ of Mg through leaves may deliver the Carbon and Nitrogen containing compounds to the seeds which effectively increases the seed quality (Gerendas and Fuhrs 2013). Quality of seeds form primary umbel was always higher than the other order umbel in all the density and foliar treatments. Highest pooled vigour index was observed in D_3 (1082), D_4 (1071), T_3 (1102) and T_6 (1089). This indicates, less plant density and spraying of foliar nutrient was promoting the seed quality in carrot. Interaction effect of density and foliar nutrient spray was not significant for all the seed quality parameters. Germination per cent of seeds from tertiary umbel was always less than seed certification

Table 2 Effect of plant density and foliar spray on seed yield parameters in carrot cv. Pusa Rudhir (Pooled data of two season 2012-13 and 2013-14)

Treatments	Number of seeds/umbel			Seed yield/umbel (g)			Percentage contribution to total seed yield			Seed yield/ plant (g)	Seed yield/ ha (q)
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		
Plant density											
D_1	1700^{b}	389^{c}	23^{d}	4.03^{b}	0.80^{d}	0.039^{d}	41.73^{a}	51.17^{c}	7.11^{c}	9.7^{d}	12.9^{a}
D_2	1742^{a}	609^{b}	27^{c}	4.24^{a}	1.33^{c}	0.045^{c}	24.05^{b}	69.94^{b}	6.01^{d}	17.7^{c}	11.8^{b}
D_3	1725^{a}	632^{b}	37^{b}	4.30^{a}	1.39^{b}	0.064^{b}	19.83^{c}	72.10^{a}	8.07^{b}	21.7^{b}	10.9^{c}
D_4	1702^{b}	692^{a}	48^{a}	4.22^{a}	1.57^{a}	0.089^{a}	16.89^{d}	72.41^{a}	10.70^{a}	25.2^{a}	10.3^{d}
CD (P=0.05)	21.71	26.11	2.74	0.09	0.03	0.002	0.58	0.74	0.34	0.29	0.23
Foliar nutrient spray											
T_1	1688^{c}	577^{bc}	32^{c}	4.14^{cd}	1.25^{bc}	0.059^{bc}	25.78	66.27	7.95^{abc}	18.3^{cd}	11.3^{bce}
T_2	1730^{b}	592^{b}	36^{b}	4.25^{b}	1.29^{b}	0.062^{ab}	25.52	66.18	8.30^{ab}	18.9^{b}	11.5^{b}
T_3	1793^{a}	621^{a}	40^{a}	4.40^{a}	1.36^{a}	0.066^{a}	24.74	66.74	8.52^{a}	20.0^{a}	12.3^{a}
T_4	1670^{c}	556^{c}	30^{cd}	4.07^{d}	1.23^{cd}	0.055^{c}	25.98	66.53	7.49^{c}	17.9^{de}	11.2^{ce}
T_5	1723^{b}	572^{bc}	32^{c}	4.21^{bc}	1.27^{bc}	0.058^{bcd}	25.84	66.36	7.80^{bc}	18.5^{bc}	11.4^{bce}
T_6	1772^{a}	588^{b}	35^{b}	4.35^{a}	1.30^{b}	0.062^{ab}	25.72	65.96	8.32^{ab}	19.1^{b}	11.5^{bc}
T_7	1644^{d}	557^{c}	28^{d}	3.95^{e}	1.20^{d}	0.053^{d}	25.78	66.79	7.44^{c}	17.3^{e}	11.1^{e}
CD (P=0.05)	26.53	24.29	2.40	0.09	0.05	0.004	NS	NS	0.71	0.60	0.30
D×T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters are statistically different. Separation done by Duncan's Multiple Range Test.

Table 3 Effect of plant density and foliar spray on seed quality of different order umbelsin carrot cv. Pusa Rudhira (Pooled data of two season 2012-13 and 2013-14)

Treatment	1000 mericarp weight (g)			Germination (%)			Vigour index			Pooled Vigour index
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	
Plant density										
D_1	2.357^{c}	2.089^{d}	1.778^{c}	71 (57.48)	67 $(55.20)^{c}$	$40(39.08)^{c}$	1024^{c}	933^{d}	507^{d}	978^{c}
D_2	2.446^{b}	2.162^{c}	1.808^{b}	73 (58.81)	71 $(57.12)^{b}$	$42(40.15)^{bc}$	1087^{b}	990^{c}	555^{c}	1039^{b}
D_3	2.489^{a}	2.240^{b}	1.844^{a}	75 (59.88)	72 $(57.99)^{ab}$	$43(41.23)^{b}$	1135^{a}	1030^{b}	593^{b}	1083^{a}
D_4	2.476^{ab}	2.286^{a}	1.858^{a}	74 (59.12)	74 $(59.00)^{a}$	$50(44.94)^{a}$	1077^{b}	1064^{a}	692^{a}	1071^{a}
CD (P=0.05)	0.04	0.04	0.02	NS	1.23	1.25	45.26	22.37	34.38	18.62
Foliar nutrient spray										
T_1	2.442^{ab}	2.188^{b}	1.816^{bc}	72 $(57.90)^{c}$	70 $(56.55)^{bc}$	$42(40.31)^{bc}$	1055^{cde}	980^{ce}	559^{cd}	1018^{cd}
T_2	2.457^{a}	2.211^{ab}	1.842^{ab}	73 $(58.82)^{bc}$	70 $(57.05)^{bc}$	$44(41.61)^{ab}$	1093^{bc}	1014b^{c}	601^{ab}	1054^{b}
T_3	2.472^{a}	2.231^{a}	1.857^{a}	75 $(60.15)^{ab}$	73 $(58.86)^{a}$	$46(42.86)^{a}$	1140^{a}	1064^{a}	642^{a}	1102^{a}
T_4	2.425^{bc}	2.180^{bc}	1.800^{cd}	72 $(58.27)^{bc}$	70 $(56.47)^{bc}$	$42(40.40)^{bc}$	1049d^{e}	976^{ce}	546^{d}	1013^{d}
T_5	2.445^{ab}	2.193^{b}	1.826^{b}	73 $(58.84)^{bc}$	72 $(57.78)^{ab}$	$45(41.87)^{ab}$	1077^{cd}	1012^{bc}	591^{bc}	1045^{bc}
T_6	2.458^{a}	2.210^{ab}	1.835^{ab}	76 $(60.85)^{a}$	73 $(58.62)^{a}$	$46(42.76)^{a}$	1137^{ab}	1041^{ab}	630^{ab}	1089^{a}
T_7	2.397^{c}	2.146^{c}	1.779d	70 $(56.99)^{c}$	69 $(55.92)^{c}$	$41(39.68)^{c}$	1015^{e}	944^{e}	538^{d}	980^{e}
CD (P=0.05)	0.03	0.04	0.03	1.93	1.52	1.63	43.63	45.09	41.45	30.62
D×T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters are statistically different. Separation done by Duncan's Multiple Range Test. Values in parenthesis are arcsine transformed value.

standard of 60% in all the treatments (Table 3).

Though highest seed yield/ha was observed in 13 plants/m^2, we recommend 5 plants/m^2 is ideal for breeder and foundation seed production without quality reduction. Since seeds form primary and secondary umbels of all the plant density recorded germination per cent higher than ISTA seed standard (60%) for carrot, even we can adopt 13 plants/m^2 for certified seed production of carrot cv. Pusa Rudhira. Harvesting seeds from tertiary umbel must be avoided to maintain higher seed quality.

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