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Research Article

Plant spacing effects on seed yield and quality of carrot cultivar T-29

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Abstract
Carrot is a direct seeded vegetable crop and plant population is primarily dependent on seed quality, besides several other factors. But, unfortunately vegetable seed production in Pakistan remained neglected and regarding standardization of numerous features for production of carrot seed crop, limited work has been done. This experiment was conducted to optimize the plant spacing for carrot seed crop. Stecklings of carrot cultivar (cv.) T-29 were planted at 15, 22.5, or 30 cm plant-to-plant spacing keeping row spacing of 75 cm. Results revealed that number of secondary and tertiary umbels per plant, yield of seed per umbel and per plant, 1000-seed weight per umbel, vigour index, germination index and seedling length of all umbel order seeds were higher for the plant spacing at 30 cm, while time taken to 50% germination (T_{50}) was significantly reduced compared to other treatments. However, appreciable (28.3% and 16.55%) increase in seed yield per plot was noted for narrow intra-row spacing (15 cm) compared to 30 and 22.5 cm spacing, respectively. Moreover, 15 cm intra-row spacing resulted in comparable seed germination (77.53%) compared with 22.5 cm (80%) and 30 cm (82%) spacing. But, seeds from closest spacing cannot be stored for long duration because of relatively low vigour (568.13) compared to 22.5 cm (630.33) and 30 cm (684.1) spacing. Therefore, for acquiring high return of good quality seed and long storage, growers can grow carrot seed crop at 22 or 30 cm spacing.

Keywords: *Daucus carota*; Planting geometry; Stecklings; Seed vigour; Umbel order

Introduction
Carrot (*Daucus carota* L.) from family Apiaceae is a biennial vegetable crop, cultivated worldwide for its roots **[1]**. Carrots of many colors provide important nutrient and bioavailable phytochemicals that act as a functional food. The storage root due to its richness in carotenoids, anthocyanins, dietary fiber, minerals and antioxidants are becoming more popular and valuable **[2]**. Carrot produces edible root for fresh consumption in one (winter) growing season and seeds in next (spring-early summer) season **[3]**.

World production of carrot is estimated to be about 27.39 million tonnes per year, on area of 9, 90 thousand hectares **[4]**. Carrot in Pakistan was grown on an area of 13.95 thousand ha during the year 2017-18 and its production was 241.91 thousand tonnes **[5]**. It occupies 3rd position among winter vegetables grown in Pakistan. Major carrot growing district in Punjab, the major carrot producing province, are Sheihupura and Qasur and contributing about 39% of the total production in Punjab [6]. Carrot varieties grown in Punjab are numerous but promising are Praline, Durga, Maha Rani, Red Core and Red Lady.

Unavailability of required quantity of good quality seed is one of the main problem faced by growers. Thus, to improve the carrot productivity locally, accessibility of quality seed is crucial [7]. Due to small scale production and low quality of local carrot seed produced in Pakistan, a large quantity of the seed accessible in the market is imported from other countries. Both, less production and poor quality can be attributed to lack of optimized seed production technology of vegetable crops, starting from seed planting to harvesting and postharvest treatment of seed [8].

Besides various factors, production of good quality seed is also affected by umbel position (primary, secondary or tertiary) and planting density. Seeds from primary and secondary umbel orders are generally of superior quality compared to tertiary umbels [9]. Therefore, optimum spacing between plants play crucial role in the yield and seed quality of carrot [10]. Planting pattern significantly influences the encompassing condition of the seed crop field, which alters the harvest phenology [11], eventually influencing the yield [12] and seed quality [13].

Optimized plant spacing is of prime importance to proliferate the biomass production and nutritional availability to plants and ultimately affect the seed quality [14, 15]. Optimal row spacing among the crop plants helps to avoid shading effect on plants as well as competition for soil moisture and nutrient elements among the plants. Appropriate plant spacing is essential for maximum seed yield of carrot because it minimizes competition for nutrition, light and water [16]. Optimal row spacing in forage turnip significantly influenced seed yield and yield components [17]. Likewise, attack of diseases (*Alternaria* sp.) in radish [18] and the crop lodging was observed in narrow spaced seed crops [17, 18].

Previous study indicated that narrow plant spacing (15 cm), keeping 60 cm inter-row spacing, resulted in highest seed yield of carrot cv. T-29 compared to 22.5 or 30 cm spacing [19], but impact of various spacings on seed quality was not assessed in that study. Hence, this study was conducted to find out the most suitable intra-row spacing for producing higher yield of good quality seed of carrot cv. T-29.

Materials and methods

Experimental site

Experiment was conducted at Vegetable Experimental Area (Latitude 31°31 N, Longitude 73° 10 E and altitude 213 m) and Vegetable Seed Lab, Institute of Horticultural Sciences, University of Agriculture Faisalabad Pakistan, to optimize the plant spacing for improving carrot seed yield and quality.

Experimental details

Carrot cv. T-29 seeds were sown on both sides of raised beds prepared 75 cm apart. First irrigation just after seed sowing was applied, while later irrigations were applied depending upon the requirement of crop. Mature roots of carrot were used for preparation of stecklings 120 days after sowing. Small sized and poor coloured roots along with, split, damaged and branched roots were discarded and healthy large sized roots with 25-30 cm long and 7-9 cm in width [19], were chosen to make stecklings for seed production. Stecklings were prepared by removing lower 1/3rd portion of the root and also keeping leaf bases (about 5 cm) intact. For plantation of stecklings, land was prepared to a good tilth and one third dose of nitrogen, full dose of phosphorus and potash was applied before ridges preparation, however remaining nitrogen was applied in two splits [20]. Stecklings having uniform size were planted at the top of ridges, which were 75 cm apart, at three different spacings viz., S_1 (15 cm), S_2 (22.5 cm), S_3 (30 cm). Field was irrigated after plantation of stecklings and sprayed with Stomp Xtra (FMC Limited) within 24 hours of irrigation. Seed crop was harvested 120 days after planting of stecklings.

Data collection

Number of umbels per plant and yield traits (seed weight of different order umbels per plant and plot) were recorded. Quality traits (1000-seed weight, germination percentage, seedling vigor index, germination index, time taken to 50 percent germination [T_{50}]) and seedling length were studied for seeds from umbels of various orders, essentially as mentioned elsewhere [20]. Sample size for data collection was ten plants or seedlings, selected randomly, in case of plants in field and germination test, respectively.

Seed quality assessment

Seeds from three above mentioned umbel orders were extracted separately and used to determine 1000-seed weight as well as germination and vigour related parameters. Germination test was accomplished for 7 days at 24 ± 2 ^{0}C, with four replicates of 25 seeds harvested from all umbels order for each treatment following rules of Association of Official Seed Analysts (AOSA) [21]. It was performed six months after harvesting, at the time of sowing of carrot root crop, to provide a true picture of seed germination for growing season. Seedling length of ten normal seedlings was measured with the help of measuring scale in each replication. Vigour index was calculated as described by [22], while time taken to 50 percent germination (T_{50}) was determined as described by [23]. Germination index (GI) was calculated as described by the AOSA [24].

Experimental layout and statistical analysis

The experiment was conducted by arranging treatments according to randomized complete block design with three replication of each treatment in field experiment while four replicates in germination trial. The data collected were analyzed statistically by using the analysis of variance technique in statistical package Statistix 8.1. Difference among treatments means at 5% probability level were compared by using Tukey's test.

Results

Planting geometry of carrot seed crop significantly affected the number of umbels per plant of cv. T-29 (Table 1). Maximum secondary umbels per plant (9.85) were documented with widest spacing at 30 cm, but were noted lowest (7.61) with plant spacing at 15 cm. Number of secondary umbels were 29.4% higher at widest spacing, i.e. 30 cm, compared with closest (15 cm) spacing. Highest tertiary umbels per plant (9.02) exhibited at 30 cm spacing that was statistically alike to 22.5 cm spacing, being 17.7% more number of tertiary umbels per plant compared with the closest spacing at 15 cm (Table 1).

Seed production of carrot was significantly affected by the plant spacing. Seed weight per umbel differed significantly among the three spacings and were significantly higher at widest spacing (Table 1). Plants spaced 30 cm apart produced higher seed weight from primary (8.96 g), secondary (22.83 g) and tertiary umbels (8.96 g) than those spaced 15 cm apart, being 25.8, 33.8 and 20.6% higher seed weight than the closest spacing from all umbels order i.e. primary, secondary and tertiary umbels, respectively. Highest planting density at 30 cm gave noticeably (28.9%) higher yield of seed per plant (40.76 g) as compared to other spacings but exhibited the lowest seed yield per plot (693.1 g). Seed yield per plot was highest at 15 cm spacing and exhibited 28.3% increase

(889.4 g) at closest spacing compared with the widest (30 cm) spacing (Table 1).

Planting density effects on seed quality were more variable. Weight of 1000-seeds increased at wider plant spacing. Higher value of 1000-seed weight from primary (4.29 g), secondary (2.86 g) and tertiary umbels (1.69 g) was observed for spacing at 30 cm, while, it was observed minimum for spacing at 15 cm (3.45, 2.39 and 1.26 g, respectively), i.e. 24.3, 19.6 and 34.1% higher than the closest (15 cm) spacing from all umbels order, respectively (Table 2). However, there was no significant difference in germination percentage of seeds from primary and secondary umbels of plants spaced 15 cm, 22.5 cm and 30 cm, but, germination percentage of tertiary umbel seeds (64.0%) of 30 cm spaced plants was highest followed by 22.5 cm spaced plants (62.0%) and minimum for 15 cm spaced plants (58.6%) (Table 2). Vigour index of seeds from all umbel order were significantly altered due to plant spacing (Table 3).

Table 1. Impact of spacing on number of umbels and seed yield of carrot cv. T-29

Treatments (Intra-row Spacing)	Number of umbels per plant		Seed yield (g)				
	Sec. umbels	Ter. Umbels	Pri. umbel	Sec. umbels	Ter. umbels	Per plant	Per plot
S1 (15 cm)	7.61 b	7.66 b	7.12 c	17.06 c	7.43 c	31.62 c	889.4 a
S2 (22 cm)	8.05 b	8.56 a	7.86 b	20.03 b	8.12 b	36.02 b	742.2 b
S3 (30 cm)	9.85 a	9.02 a	8.96 a	22.83 a	8.96 a	40.76 a	693.1 c

Mean values having similar letters in a column are statistically similar to each other (P≤0.05) according to Tukey Test. Primary (Pri.); Secondary (Sec.); Tertiary (Ter.)

Table 2. Spacing effects on thousand seed weight and germination of primary, secondary and tertiary umbel seeds of carrot cv. T-29

Treatments (Intra-row Spacing)	Weight of 1000 seeds (g) from			Germination (%) of seeds from		
	Pri. umbel	Sec. umbels	Ter. umbels	Pri. umbel	Sec. umbels	Ter. umbels
S1 (15 cm)	3.45 c	2.39 b	1.26 c	88.0 a	86.0 a	58.6 b
S2 (22 cm)	3.86 b	2.64 a	1.53 b	90.0 a	88.0 a	62.0 ab
S3 (30 cm)	4.29 a	2.86 a	1.69 a	92.0 a	90.0 a	64.0 a

Mean values having same letters in a column are statistically similar to each other (P≤0.05) according to Tukey Test. Primary (Pri.); Secondary (Sec.); Tertiary (Ter.)

Table 3. Vigour index and germination index of primary, secondary and tertiary umbel seeds of carrot cv. T-29 in response to mother plant spacing

Treatments (Intra-row Spacing)	Vigour index of seeds from			Germination index of seeds from		
	Primary umbel	Secondary Umbels	Tertiary umbels	Primary umbel	Secondary Umbels	Tertiary umbels
S1 (15 cm)	724.6 c	696.3 c	283.5 b	30.6 b	29.1 b	13.0 b
S2 (22 cm)	800.5 b	768.2 b	322.3 ab	34.1 a	32.3 a	15.3 ab
S3 (30 cm)	867.2 a	822.0 a	363.1 a	36.0 a	34.0 a	18.1 a

Mean values having same letters in a column are statistically similar to each other (P≤0.05) according to Tukey Test. Primary (Pri.); Secondary (Sec.); Tertiary (Ter.)

It can be observed from the results that highest vigour index of seeds from primary (867.2), secondary (822.0) and tertiary (363.1) umbels was noticed in the seed obtained from the plant grown at wider (30 cm) spacing. Moreover, vigor index of seeds collected from 30 cm spaced plants was 19.67, 18.05 and 28.07% higher from all umbels order respectively, compared with those spaced 15 cm apart. Germination index was highest for widest plant spacing at 30 cm and increased up to 17.64, 16.8 and 39.2% from primary, secondary and tertiary umbel order seeds, respectively, compared to narrowest (15 cm) plant spacing (Table 3).

Results revealed significant differences for time taken to 50 percent germination (T_{50}) among spacing levels (Table 4). Seed from widely spaced plants exhibited reduced time for 50 percent germination i.e. 14.8, 24.1 and 21.2% reduction from primary, secondary and tertiary umbels, respectively, at 30 cm spacing. It can be observed from the results that seedling length was maximum for seeds of primary (9.43 cm), secondary (9.13 cm) and tertiary umbel order (5.66 cm) of widely spaced plants (30 cm), i.e. 14.5, 12.7 and 17.1% higher than the closest (15 cm) spacing.

Table 4. Effect of spacing on T_{50} and seedling length of primary, secondary and tertiary umbel seeds of carrot cv. T-29

Treatments (Intra-row Spacing)	T_{50} (days) of seeds from			Seedling length (cm) of seeds from		
	Pri. umbel	Sec. umbels	Ter. umbels	Pri. umbel	Sec. umbels	Ter. umbels
S1 (15 cm)	0.85 a	0.87 a	1.32 a	8.23 c	8.1 b	4.83 b
S2 (22 cm)	0.77 ab	0.78 a	1.29 a	8.83 b	8.66 a	5.21 b
S3 (30 cm)	0.74 b	0.66 b	1.04 b	9.43 a	9.13 a	5.66 a

Mean values having same letters in a column are statistically similar to each other ($P \leq 0.05$) according to Tukey Test. Primary (Pri.); Secondary (Sec.); Tertiary (Ter.)

Discussion

Row spacing alters structure of plant, photosynthetic rate and distribution of dry matter in several agronomic and horticultural crops **[11, 15, 25, 26]**. Total umbels per plant were increased through widest (30 cm) plant spacing. The difference in spacing brought significant variation in seed yield components. Number of harvested umbels per plant was higher in wider spacing than the closer spacing, which seems to be mainly due to less competition for nutrition and light. This less competition might have augmented more branching, ultimately producing more umbels per plant. Wider spacing (60 x 60 cm) resulted in higher umbels per plant, greater mass and size of umbel in carrot crop **[27]**. Similar results were found in cauliflower by Rahman *et al.* **[26]**.

Results depicted that seed yield parameters were greatly influenced by plant spacing and widest spacing produced highest seed weight per umbel of carrot seed crop. This increased production of seed per plant may be owing to well establishment of the plant which in turn resulted in production of maximum umbels per plant. Enhanced seed quantity at wider spacing due to less competition than dense spacing in rice was also stated by Dass *et al.* **[28]**. In contrast, seed yield per plot was higher for closely spaced plants because plants population was high that eventually enhanced seed production. Previously, increased seed yield of carrot due to closely spaced plants has been reported by some researchers **[19, 29, 30]**. Higher seed yield in closely spaced plots than at wider spacing had also been reported in forage turnip **[17]**. Similarly, seed yield of fodder radish was enhanced with increase in plant population due to close plant spacing **[18]**, which confirms our outcomes.

Seed quality is assessed by determining seed size, seed germination potential and vigour index. It was observed that weight of 1000-seeds, which reflects seed size and ultimately improve seed yield and its quality [31], was higher from widely spaced plants compared with closely spaced plants indicating better uptake of nutrients and improved photosynthetic efficiency of plants and photosynthate accumulation in developing seeds [32]. Increase in 1000-grain weight of rice has been reported at wider spacing than closer spacing by [13]. Wider spacing had substantial effects on weight of 1000 seed of cotton and onion seeds but did not affect the germination percentage [33, 34]. In line with these results of other researchers, carrot seed crop spacing did not influence germination of primary and secondary umbel seeds but slightly decreased germination of seeds collected from 22.5 and 15 cm spaced plants. Previously, it has been reported that spacing did not affect germination but improved vigour in radish [18] because of adequate photosynthates availability to be accumulated in seeds under wider spacing conditions [35]. Same pattern was observed in vigour of seeds from all umbel orders of widely (30 cm) spaced plants that was significantly better than seed vigour of closely (15 cm) spaced plants. Moreover, germination index also indicated that both 30 and 22.5 cm spaced plants were statistically similar and better than 15 cm spaced plants. It is an already established fact that seed germination and vigour are correlated with seedling emergence of soybeans in field [36, 37]. Yagushi *et al.* [38] also described that there was strong positive correlation between soybean seedling emergence in field and vigour index after six months of storage. Moreover, they showed that high quality seed lots exhibiting high germination and vigour maintained their germination and vigour even when stored under controlled (20 °C and 70% R.H.) and ambient conditions. Therefore, it can be concluded from the results that seeds of 15 cm spaced plants can be stored, but for a shorter duration (probably up to one year under normal storage conditions) compared to 30 cm spaced plants. So, seeds from closely spaced plants can reliably be used for sowing during normal season. But, such seed should be used with caution for early season sowing, when temperature is high during late summer months in Punjab; usually at higher rate than normal, because of low vigour

Conclusion

Seed obtained from widely spaced (30 cm) plants was better in almost all aspects except seed yield per plot that was higher for narrow intra-row spacings (15 cm) but at the expense of seed quality. So, 30 cm plant spacing would be beneficial for enhancing seed quality of carrot. Based on this study, it may be concluded that carrot seed crop (stecklings) should be planted at spacing of 30 cm for higher quality seed followed by 22 cm.

Authors' contributions

Conceived and designed the experiments: K Ziaf, Performed the experiments: A Noor, Analyzed the data: MA Ghani, Contributed materials/ analysis/ tools: CM Ayub & M Amjad, Wrote the paper: K Ziaf & I Ahmad.

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