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Optimizing sowing dates and spacing of carrot (*Daucus carota* L.) varieties for higher productivity, quality and economics in arid region of Rajasthan

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ABSTRACT

The study was conducted at the College of Agriculture, Jodhpur, to evaluate the effects of staggered sowing and plant spacing on the growth, yield, quality, and economics of two carrots (Daucus carota L.) varieties, 'Pusa Rudhira' and 'Pusa Vrishti'. The experiment was laid out in a Factorial Randomized Block Design with three replications, incorporating three spacings (20 cm × 10 cm, 30 cm × 10 cm, and 30 cm × 20 cm) and four sowing dates (10th August, 25th August, 10th September, and 25th September). Results indicated that 'Pusa Vrishti' achieved significantly higher growth parameters, with a plant height of 35.9 cm and fresh weight of 90.1 g plant⁻¹, whereas 'Pusa Rudhira' excelled in yield and quality, producing a root yield of 23.8 t ha⁻¹ and β-carotene content of 4.42 mg per 100g. Wider spacing (30 cm × 20 cm) enhanced growth attributes but closer spacing (20 cm × 10 cm) resulted in higher root yield (24.5 t ha⁻¹). Late sowing on 25th September produced the best quality roots, with a fresh root weight of 127.3 g, while the earliest sowing on 10th August yielded the highest economic returns (Rs. 309,028 ha⁻¹). The study concludes that optimizing sowing dates and plant spacing, along with the selection of suitable varieties, can significantly improve carrot productivity and profitability in arid regions.

Keywords: Carrot, staggered sowing, plant spacing, root yield, ß-carotene

INTRODUCTION

Carrot (*Daucus carota* L.) is a highly valued cool-season root vegetable, cultivated primarily for its edible roots. In temperate climates, carrots can be cultivated year-round, while in tropical and subtropical regions, they are predominantly grown during the winter season (Bose *et al.*, 2003). The major carrot-growing districts in Rajasthan include Jodhpur, Alwar, and Sri Ganganagar. Recently, the area under carrot cultivation in western arid Rajasthan especially in Jodhpur district has been rapidly increasing. However, due to the lack of appropriate agronomic practices, such as optimal plant spacing, suitable sowing time, and the use of appropriate varieties, the productivity, quality, and economic returns of carrot crops remain low. Carrot cultivation is labor-intensive, and the market price often drops during peak season, resulting in low returns for farmers. Additionally, farmers frequently use seeds of non-descript varieties without following optimal spacing and sowing time recommendations, further affecting yield and quality.

Several factors influence the growth, yield, quality, and economics of carrot production. The agronomic practices can be adjusted to maximize yield, and staggered sowing can extend the harvest period, enabling farmers to fetch better market prices and maximize returns. Carrots are highly sensitive to temperature and photoperiodic requirements. The optimal temperature range for carrot growth and color development is 15-21°C. Harvesting at the proper stage of maturity is crucial, as roots harvested too early or too late become fluffy, hard, and unfit for consumption. Moreover, temperatures above 21°C and below 15°C can lead to increased root splitting, reduced firmness, and lower carotene content (Lee and Kader, 2000).Yield improvement in carrots can be substantially achieved by growing improved varieties that match the thermo-photoperiodic requirements. Proper sowing time is critical for aligning the growth stages of the variety with favorable environmental conditions. Plant spacing is another crucial aspect, as maintaining optimal plant population density ensures efficient resource utilization and minimizes inter-plant competition (Agyekum, 1999). To expand the availability of carrots throughout the early and late growing seasons, optimizing plant spacing and sowing time, along with selecting suitable varieties, is essential. This approach can enhance the economic returns of carrot cultivation by avoiding market gluts and distress sales. Therefore, the present investigation aimed to determine the effects of staggered sowing and spacing on root growth, yield, quality, and the economics of carrot varieties.

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MATERIALS AND METHODS

The experiment was conducted during the *Kharif* 2018 at the College of Agriculture, Mandor, Jodhpur, located at an altitude of 231 meters above mean sea level, between 26°15" to 26°45" North latitude and 73°00" to 73°29" East longitude. This region falls under agro-climatic zone Ia, the Arid Western Plains Zone of Rajasthan. The soil of the experimental field is sandy-loam in texture, slightly alkaline in reaction, poor in organic carbon (0.13%), low in available nitrogen (174 kg ha^{-1}), medium in available phosphorus (20.2 kg ha^{-1}), and high in available potassium (325 kg ha^{-1}). During the crop season the maximum and minimum temperatures ranged from 39.4°C to 22.1°C and 27.4°C to 13.2°C, respectively. The total rainfall received during the crop season was 81.0 mm.

The experiment was laid out in a Factorial Randomized Block Design with three replications. The gross plot size was 2.70 m × 2.10 m. The treatments comprised two varieties (Pusa Rudhira and Pusa Vrishti), three spacings (20 cm × 10 cm, 30 cm × 10 cm, and 30 cm × 20 cm), and four sowing dates (10 August, 25 August, 10 September, and 25 September 2018). Healthy seeds of the varieties Pusa Rudhira and Pusa Vrishti were sown as per the sowing date and spacing treatments. Two to three healthy seeds were placed at a depth of 1.5 cm. Irrigations were given at 5-7 day intervals depending on the moisture condition of the experimental plot, maintaining uniform soil moisture throughout the crop growth period. Harvesting was performed manually for each sowing date treatment when the carrot roots attained optimal size, color, and full maturity.

Growth parameters recorded included plant height, leaf length, number of leaves per plant at 30, 45, and 60 DAS (days after sowing), and fresh weight of aerial parts at harvest. Yield and yield attributing parameters included days to marketable maturity, root length, root diameter, core diameter, fresh weight of root and root yield. Quality parameters assessed were β-carotene content estimated by the method of AOAC (2000) and total soluble solids (TSS) content measured using an Abbe's Hand Refractometer from roots of five randomly selected plants per plot. To test the significance of variations in the data obtained from parameters, the Analysis of Variance technique was employed for a randomized block design. The significance of treatment effects was tested through the F-test at a 5% level of significance, and the critical difference (CD) was calculated where results were significant.

RESULTS AND DISCUSSION

Growth Parameters

The results reveal that 'Pusa Vrishti' recorded significantly higher values for all growth parameters compared to 'Pusa Rudhira' (Table 1). Specifically, 'Pusa Vrishti' exhibited a plant height of 35.9 cm at 60 DAS, which is 13.2% higher than 'Pusa Rudhira' at 31.7 cm. Similarly, leaf length for 'Pusa Vrishti' was 34.0 cm at 60 DAS, an 8% increase over 'Pusa Rudhira' at 31.5 cm. The number of leaves per plant for 'Pusa Vrishti' reached 7.06 at 60 DAS, compared to 6.54 for 'Pusa Rudhira', reflecting an 8% improvement.

The fresh weight of the aerial part at harvest for 'Pusa Vrishti' was 90.1 g $plant^{-1}$, which is higher than 'Pusa Rudhira' at 84.8 g $plant^{-1}$. The higher biomass production by 'Pusa Vrishti' over 'Pusa Rudhira' is attributed to the genetic makeup of the cultivar, as both were cultivated under identical management and environmental conditions. The enhanced growth parameters in 'Pusa Vrishti' likely led to greater interception and absorption of radiant energy, resulting in higher photosynthesis rates and increased dry matter accumulation. Spacing significantly affected the growth parameters, with the widest spacing (30 cm × 20 cm) resulting in the highest values for plant height (36.6 cm at 60 DAS), leaf length (35.0 cm at 60 DAS), number of leaves per plant (7.19 at 60 DAS), and fresh weight of aerial part at harvest (95.3 g $plant^{-1}$). Wider spacing reduces competition for soil nutrients, moisture, carbon dioxide, and light, thus enhancing growth (Agyekum, 1999). The date of sowing also significantly influenced growth parameters (Table 1). Late sowing on 25th September resulted in the highest values for plant height (38.4 cm at 60 DAS), leaf length (35.9 cm at 60 DAS), number of leaves per plant (8.07 at 60 DAS), and fresh weight of aerial parts at harvest (101.3 g $plant^{-1}$). The favorable temperature conditions during the later sowing period likely contributed to these enhanced growth parameters.

Table 1: Effect of date of sowing and spacing on growth parameters of carrot varieties

Treatment	Plant height at 60 DAS (cm)	Leaf length at 60 DAS (cm)	Number of leaves plant/ plant at 60 DAS (cm)	Fresh weight of aerial part (g plant^{-1})
		Varieties		
Pusa Rudhira	31.7	31.5	6.54	84.8
Pusa Vrishti	35.9	34.0	7.06	90.1
SEm±	0.57	0.76	0.126	1.63
CD (p=0.05)	1.6	2.2	0.36	4.6
		Spacing		
20 x 10 cm	31.3	30.0	6.38	79.1
30 x 10 cm	33.5	33.1	6.85	87.8
30 x 20 cm	36.6	35.0	7.19	95.3
SEm±	0.69	0.94	0.154	1.99
CD (p=0.05)	2.0	2.7	0.44	5.7
		Date of sowing		
10th August	29.7	29.0	5.71	72.4
25th August	31.8	32.6	6.16	81.7
10th September	35.4	33.4	7.27	94.3
25th September	38.4	35.9	8.07	101.3
SEm±	0.80	1.08	0.178	2.30
CD (p=0.05)	2.3	3.1	0.51	6.6

Yield and yield attributing parameters

'Pusa Rudhira' exhibited significantly superior yield and yield attributing parameters compared to 'Pusa Vrishti'. The fresh weight of root for 'Pusa Rudhira' was 122.2 g plant^{-1}, 12.6% higher than 'Pusa Vrishti' at 108.5 g plant^{-1}. Additionally, 'Pusa Rudhira' had a root length of 22.1 cm, which is 21.4% longer than 'Pusa Vrishti' at 18.2 cm, and a root diameter of 3.16 cm compared to 2.94 cm for 'Pusa Vrishti', representing a 7.5% increase. Root yield per hectare for 'Pusa Rudhira' was 23.8 t ha^{-1}, 12.8% higher than 'Pusa Vrishti' at 21.1 t ha^{-1} (Table 2). The significantly higher yield and yield parameters in 'Pusa Rudhira' over 'Pusa Vrishti' might be due to its genetic potential when grown under hot arid conditions (Arthirani *et al.*, 2009). Further, the root yield of carrot is highly dependent on important yield parameters such as root length, root diameter, and fresh weight of root. Thus, due to higher yield parameters, 'Pusa Rudhira' resulted in higher root yield compared to 'Pusa Vrishti' (Polaki, 2011).The yield and yield parameters were significantly influenced by different spacing treatments. The closest spacing (20 cm × 10 cm) took significantly more days to marketable maturity (79.9 days) compared to the widest spacing (30 cm × 20 cm) at 74.6 days, a reduction of 6 days. Wider spacing also resulted in maximum root length (20.8 cm), root diameter (3.29 cm), and fresh weight of root (126.3 g plant^{-1}), representing increases of 6.7%, 22%, and 20% respectively, over the closest spacing (20 cm × 10 cm) (Table 2). These findings suggest that reduced competition for resources in wider spacing leads to enhanced growth and yield attributes (Murthy, 2014). The date of sowing significantly influenced yield parameters as well. The 25th September sowing resulted in the highest root length (22.1 cm), root diameter (3.29 cm), and fresh weight of root (127.3 g plant^{-1}), with corresponding increases of 23%, 19%, and 25% respectively, over the 10th August sowing, which recorded 18.0 cm, 2.76 cm, and 102.0 g plant^{-1} (Table 2). This trend is likely due to the more favorable temperature and environmental conditions during the later sowing period, promoting better growth and development of roots (Lee & Kader, 2000).

Quality Parameters

Among the cultivars, 'Pusa Rudhira' recorded significantly higher quality parameters compared to 'Pusa Vrishti'. The β-carotene content for 'Pusa Rudhira' was 4.42 mg per 100g, 93.7% higher than 'Pusa Vrishti' at 0.36 mg per 100g. Similarly, 'Pusa Rudhira' exhibited a higher TSS content of 9.0°Brix compared to 8.6°Brix for 'Pusa Vrishti', a 4.7% increase (Table 2). These differences are likely due to the genetic makeup of the cultivars (Polaki, 2011).

Table 2: Effect of date of sowing and spacing on days to marketable maturity, root length, root diameter, core diameter and fresh weight of root of carrot varieties

Treatments	Days to marketable maturity	Root length (cm)	Root diameter (cm)	Core diameter (cm)	Fresh weight of root (g plant^{-1})	Root yield (t ha^{-1})	β-Carotene content (mg/100 g)	TSS (^{0}Brix)
Varieties								
Pusa Rudhira	73.9	22.1	3.16	1.41	122.2	23.8	4.42	9.0
Pusa Vrishti	80.4	18.2	2.94	1.48	108.5	21.1	0.36	8.6
SEm±	0.90	0.31	0.059	0.025	1.95	0.37	0.026	0.08
CD (p=0.05)	2.6	0.9	0.17	NS	5.6	1.1	0.07	0.2
Spacing								
20 x 10 cm	79.9	19.5	2.70	1.32	105.0	24.5	2.41	8.7
30 x 10 cm	77.1	20.2	3.15	1.45	114.8	22.6	2.36	8.8
30 x 20 cm	74.6	20.8	3.29	1.56	126.3	20.2	2.40	9.0
SEm±	1.11	0.38	0.073	0.031	2.39	0.46	0.032	0.10
CD (p=0.05)	3.2	NS	0.21	0.09	6.8	1.3	NS	NS
Date of sowing								
10th August	81.7	18.0	2.76	1.19	102.0	19.0	2.21	8.0
25th August	78.1	19.5	2.96	1.33	109.4	21.1	2.29	8.5
10th September	75.4	21.0	3.19	1.52	122.7	23.8	2.45	9.2
25th September	73.7	22.1	3.29	1.73	127.3	25.8	2.60	9.6
SEm±	1.28	0.44	0.084	0.036	2.76	0.53	0.037	0.12
CD (p=0.05)	3.6	1.2	0.24	0.10	7.9	1.5	0.10	0.3

The quality parameters were not significantly influenced by different spacing treatments, although higher TSS values were observed with wider spacing such as 30 cm × 10 cm and 30 cm × 20 cm (Table 2). The enhanced quality parameters in wider spacing might be due to better utilization of nutrients, moisture, and light (Alves *et al.*, 2010).Different sowing dates significantly influenced root quality traits. Late sowing on 25th September significantly increased the quality parameters, with β-carotene content reaching 2.60 mg per 100g and TSS at 9.6°Brix, compared to the earliest sowing on 10th August with β-carotene content of 2.21 mg per 100g and TSS of 8.0°Brix (Table 2). These results are consistent with the findings of Yucel (1992), who reported a highly positive correlation between climatic factors and root quality.

Table 3: Interaction effects of varieties and date of sowing

Treatment	10th August (D_1)	25th August (D_2)	10th September (D_3)	25th September (D_4)
Fresh weight of root (g plant^{-1})				
Pusa Rudhira	102.7	113.1	133.7	139.4
Pusa Vrishti	101.3	105.8	111.8	115.2
SEm±			3.90	
CD (p=0.05)			11.1	
Root yield (t ha^{-1})				
Pusa Rudhira	19.4	22.2	25.0	28.5
Pusa Vrishti	18.6	20.0	22.6	23.0
SEm±			0.75	
CD (p=0.05)			2.1	
β-Carotene content (mg/100 g)				
Pusa Rudhira	4.08	4.27	4.56	4.76
Pusa Vrishti	0.31	0.34	0.34	0.45
SEm±			0.052	
CD (p=0.05)			0.15	
TSS (^{0}Brix)				
Pusa Rudhira	8.0	8.6	9.4	10.1
Pusa Vrishti	7.9	8.4	9.1	9.1
SEm±			0.17	
CD (p=0.05)			0.5	

Table 4: Economics of carrot varieties under different dates of sowing and spacing

Treatments	Total cost (Rs. ha^{-1})	Gross Returns (Rs. ha^{-1})	Net Returns (Rs. ha^{-1})	B:C Ratio
Varieties				
Pusa Rudhira	71429	326920	255491	3.58
Pusa Vrishti	71429	293427	221998	3.11
Spacing				
20 x 10 cm	112129	338733	226604	2.02
30 x 10 cm	100329	313968	213639	2.13
30 x 20 cm	90119	277819	187700	2.08
Date of sowing				
10^{th} August	71429	380457	309028	4.33
25^{th} August	71429	316659	245230	3.43
10^{th} September	71429	285725	214296	3.00
25^{th} September	71429	257853	186424	2.61

Interaction Effect of Variety, Spacing and Date of Sowing

The interaction between variety and date of sowing was significant for fresh weight of root, and root yield per hectare (Table 3). 'Pusa Rudhira' sown on 25th September recorded the highest values for fresh weight of root (139.4 g $plant^{-1}$), root yield (28.5 t ha^{-1}), followed by the same variety sown on 10th September. The interaction of varieties and date of sowing was also significant for β-carotene and TSS content, with 'Pusa Rudhira' sown on 25th September recording the highest β-carotene content (4.76 mg per 100g), and the same variety sown on 10th August showing the highest TSS content (10.1°Brix) (Table 3). These findings align with earlier reports by Polaki (2011).

Economics

The economic analysis (Table 4) indicates that 'Pusa Rudhira' recorded higher net returns (Rs. 255,491 ha^{-1}) and B:C ratio (3.58) compared to 'Pusa Vrishti' (Rs. 221,998 ha^{-1} and 3.11, respectively). This is attributed to the higher yield of 'Pusa Rudhira'. Among different spacings, the maximum net returns (Rs. 226,604 ha^{-1}) were recorded in the closest spacing (20 cm × 10 cm), while the highest B:C ratio (2.13) was observed in the 30 cm × 10 cm spacing (Table 4). This variation is likely due to differences in input costs and root yield under different spacings. The highest net returns (Rs. 309,028 ha^{-1}) and B:C ratio (4.33) were recorded for the 10th August sowing, while the lowest net returns (Rs. 186,424 ha^{-1}) and B:C ratio (2.61) were observed for the 25th September sowing (Table 4). The early sown crop fetched higher returns with no extra cost involved in raising the crop, contributing to higher profitability.

CONCLUSION

The study concludes that optimizing sowing dates and plant spacing significantly enhances carrot productivity and quality. 'Pusa Vrishti' demonstrated superior growth parameters, while 'Pusa Rudhira' yielded higher root production and quality. Late sowing (25th September) and wider spacing (30 cm × 20 cm) improved root quality, whereas early sowing (10^{th} August) maximized economic returns.

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