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Growth, Yield and Quality Performances of Selected Carrot Varieties Under Drought Stress

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ABSTRACT

A study was conducted at the Horticulture Farm and Postgraduate Laboratory of the Department of Horticulture, Bangladesh Agricultural University, Mymensingh, from November 2022 to February 2023, to evaluate the performance of growth, yield, and quality of 11 carrot varieties under drought stress. The varieties included Kuroda, New Kuroda, Kuroda-35, King Kuroda, Shin Kuroda, Kuroda Improved, Shidur, BAU Gajor-5, Prima Agroflora, Bankim Keshor, and Pusha Keshor. The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. In order to account for the drought stress, no irrigation was applied after 30 days of sowing until carrot harvest. Growth parameters, such as plant height, number of leaves plant^{-1}, and leaf area; yield-contributing parameters, including root length, diameter, individual weight; plot yield and quality parameters, such as root cracking, branching, rotting, total soluble solids (TSS), and dry matter content, were recorded. Significant variations were noted among the varieties. King Kuroda excelled with maximum root length (17.31 cm), root weight (164.07 g), yield per plot (5.23 kg), gross yield (34.89 t ha^{-1}), and marketable yield (30.07 t ha^{-1}). Shin Kuroda recorded the highest TSS (13.13%), while King Kuroda showed superior dry matter content in leaves (21.33%) and roots (9.85%). BAU Gajor-5 had no cracked roots, but it showed the minimum marketable yield (11.67 t ha^{-1}) followed by Prima Agroflora (12.42 t ha^{-1}). Shin Kuroda had the lowest branched root percentage (1.09%). Varieties Kuroda-35 and Pusha Keshor also consistently excelled in growth, yield, and quality attributes under drought stress. Therefore, out of eleven varieties, King Kuroda, Kuroda-35, and Pusha Keshor were found to perform better in terms of growth, yield, and quality under drought stress.

1. Introduction

Carrot (*Daucus carota* L.), a dicotyledonous, herbaceous biennial root vegetable belonging to the family Apiaceae, is a highly nutritious crop grown especially in temperate and subtropical regions (Selvakumar *et al.,* 2019). It is native to tropical Asia and Africa and ranks among the top 10 main vegetables produced globally, after tomatoes, onions, cabbage, cucumbers, and eggplant (FAO, 2021). Carrots are rich in beta-carotene, which acts as a precursor of vitamin A and is a crucial protectant of phytochemical processes (Terletskaya *et al.,* 2021). Beta-carotene helps protect plants from stress damage by quenching triplet chlorophyll (Farooq *et al.,* 2009). Carrots contain soluble sugars, including fructose, glucose, and sucrose. During maturity, sucrose buildup in carrot roots increases, which depends on soil moisture, influencing taste and flavor (Ombódi *et al.,* 2015).

Carrots are abundant in important vitamins and minerals, and from a half- cup of carrots, we can get 73% vitamin A and 9% vitamin K of our daily needs. Carrots are rich in antioxidants and offer numerous health benefits. The lutein in yellow carrots supports eye health and prevents age-related macular degeneration. Carotenoids in orange or yellow carrots and anthocyanins in red/purple carrots fight free radicals and protect against cancer. Carrots contain vitamin C, which strengthens the immune system by supporting iron absorption and infection defense. As a non-starchy vegetable, loaded with fiber, they can help with constipation, lower blood sugar, and manage diabetes. Containing vitamin K and calcium, they strengthen bones. In foods, carrot roots can be eaten raw, boiled, fried, or steamed, or added to cakes, puddings, jams, or preserved, or prepared as a juice. Carrot leaves can be eaten raw or cooked for different purposes.

Despite their nutritional benefits, carrot cultivation in Bangladesh is limited due to a need for more awareness and production knowledge. According to the Bangladesh

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Bureau of Statistics (BBS), in the 2022-2023 period, Bangladesh produced 27,000 tons of carrots over 2,428 hectares, resulting in an average yield of 11.13 t ha^{-1} (BBS, 2024). However, carrot yield per unit area still stays below the demand. In Bangladesh, the average yield is very low compared to other carrot-producing countries in the world like Belgium (67.25 t ha^{-1}), Netherlands (57.02 t ha^{-1}) and Sweden (64.16 t ha^{-1}) (FAO, 2017). In most developing countries, however, carrot yields per unit area remain below the recommended world average. One of the reasons for such low yields is limited information regarding the effects of drought on the growth and yield of carrots. Carrot production can be a viable enterprise for small-scale, resource-limited farmers as it is a short-duration crop with high yields per unit area, making it a profitable option (Bartaseviciene and Pekarskas, 2007; Ahmad *et al.,* 2005).

Climate change has disrupted the natural ecology, leading to extreme temperatures, altered rainfall patterns, droughts, and floods. It also has had an impact on the production of carrots (Ren *et al.,* 2021; Zhang *et al.,* 2021; Kowalczyk and Kuboń, 2022). Drought stress is usually caused by reasons like decreased precipitation, lower water tables, and climate change (Vadez *et al.,* 2012; Wang *et al.,* 2022). It is the main abiotic stressor affecting plant growth (Duan *et al.,* 2021; Zhu *et al.,* 2021). Abiotic stress may affect carrots, and drought stress can negatively impact both the quantity and quality of carrots produced (Razzaq *et al.,* 2017; Rashid *et al.,* 2024). Cultivars with higher dry matter content are more tolerant to drought stress (Abid *et al.,* 2018). Moreover, it is needed to develop cultivars that can withstand abiotic stress conditions. Very limited work has been done on carrot cultivars under drought-stress conditions. Therefore, the current experiment was undertaken to study the performance of carrot varieties under drought stress.

2. Materials and Methods

2.1. Experimental location

The experiment was conducted at the Horticulture Farm and Postgraduate Laboratory at the Department of Horticulture, Bangladesh Agricultural University, Mymensingh during the period from November 2022 to February 2023. The soil of the experimental area was sandy loam in texture, belonging to the Old Brahmaputra Floodplain Alluvial Tract (UNDP, 1988). The selected plot was high land, fertile, well-drained, with a pH of 6.7.

2.2. Experimental materials

The experiment was designed to study the performance of 11 carrot varieties in terms of growth, yield, and quality under drought stress. The seeds were collected from Krishan Agro, Natun Bazar, Mymensingh, Rangpur, and the USA. The varieties included Kuroda, New Kuroda, Kuroda-35 (orange), King Kuroda (orange), Shin Kuroda (orange),, Kuroda Improved (orange), and Shidur (orange) are originated from Japan, BAU Gajor-5 (yellow) is originated in Bangladesh, Prima Agroflora (yellow), Bankim Keshor (light red), and Pusha Keshor (red) are originated from India.

2.3. Experimental design

A single-factor experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The entire experimental area was divided into three equal blocks. Each block was further divided into 11 plots, making a total of 33 (11 × 3) unit plots. The size of each unit plot was 1.5 m × 1 m. A distance of 0.3 m between plots and 0.5 m between blocks was maintained to facilitate various intercultural operations.

2.4. Intercultural operations

The land was ploughed and cross-ploughed, followed by laddering, to achieve a good tilth. All weeds and stubbles were removed from the field. During final land preparation, Furadan 5G was applied at a rate of 8 kg ha^{-1} to protect young plants from insect infestation. The experimental plot was treated with the recommended doses of NPKS fertilizers i.e. urea @250 kg/ha, TSP @200 kg/ha, MoP @200 kg/ha, gypsum @100 kg/ha (Ahmmed et al., 2018). The entire amount of fertilizers was applied as a basal dose during the final land preparation. Urea was applied in three installments at 30, 45, and 60 days after sowing.

Before sowing, the seeds were soaked in water for 24 hours and then wrapped in a thin cloth. To remove excess moisture, the soaked seeds were spread over polythene sheets for two hours to facilitate quick germination. The seeds were sown in lines at a depth of 1.5 cm. Each plot contained four lines, with a distance of 25 cm maintained between lines. The sowing date was 30 November 2022. Various intercultural operations, such as thinning was done at 15 and 30 days after seed sowing and weeding was performed at every 7 days intervals starting from 15 days after seed sowing. In total, the plot was irrigated three times. Light irrigation was applied immediately after sowing (1st irrigation), while the second and third irrigations were given at 15 and 30 days after sowing. No further irrigation was provided after the third irrigation to induce drought stress until the carrot harvest.

The crop was harvested at 90 days after sowing, on 14 February 2023. Ten randomly selected plants were harvested from each unit plot, along with the remaining plants in the plot, for data collection. Data were recorded four times during different stages of crop growth (30, 45, 60, and 75 days after sowing). The growth parameters studied included plant height, the number of leaves per plant, and leaf area.

2.5. Parameters studied

Data on yield and quality parameters were collected after harvesting. The parameters studied were root length (cm), root diameter (cm), individual root weight per plant (g), root weight per plot (kg), gross root yield per hectare (t), marketable root yield per hectare (t), root dry matter content (%), leaf dry matter content (%), cracked roots (%), rotten roots (%), branched roots (%), and total soluble solids (%). The collected data were analyzed, and mean differences were adjudged using the least significant difference (LSD) test at 5% and 1% levels of probability (Gomez and Gomez, 1984).

1a

1b

1c

1d

1e

1f

1g

1h

Plate 1. Pictorial view of 1a. Land preparation, 1b. Seed sowing, 1c. Raising of seedlings. 1d. Vegetative growth, 1e. Harvesting, 1f. Data collection (Root diameter, 1g. Data collection (Leaf weight) and 1h. Data collection (Root weight)

3. Results and Discussion

3.1. Plant height

Variety had a significant effect on carrot morphological characteristics such as plant height (Table 1). All the varieties reached their maximum plant height at 75 DAS. Of the eleven varieties examined, Pusha Keshor had the highest plant height (128.27 cm), followed by BAU Gajor -5 (126.23 cm), and Kuroda-35 had the lowest plant height (50.67 cm). Shidur (55.00 cm) was the next plant in the middle height group, closely followed by King Kuroda (55.22 cm), New Kuroda (57.77 cm), Kuroda (59.07 cm), Bankim Keshor (62.87 cm) and Prima agroflora (87.17 cm). The variations in the plant height might be due to the varietal genetic characters. Plant height is increased due to vigorous cell division and expansion, which are impacted by protein synthesis (Choudhary *et al.,* 2023).

3.2. Number of leaves per plant

Significant variation was observed in number of leaves per plant (Table 1). Kuroda-35 was found to be superior over others with respect to number of leaves per plant (11.07) followed by Kuroda (11.04), Kuroda Improved (10.93), Pusha Keshor (10.93), BAU Gajor-5 (10.87) and King Kuroda (10.74), respectively while New Kuroda recorded the minimum number of leaves per plant (10.20) closely followed by Shin Kuroda (10.20), Shidur (10.33), Prima Agroflora (10.33) and Bankim Keshor (10.33), respectively. The rate of leaf commencement, which may be an innate characteristic of each genotype, was most likely the cause of the variance in leaf counts between genotypes (Kushwah *et al*., 2019).

3.3. Leaf area

The leaf area was significantly varied between different varieties of carrot (Table 1). As per data recorded, it is found that the maximum leaf area was recorded in Bankim Keshor (1226.19 cm^2) followed by BAU Gajor-5 (910.74 cm^2), prima Agroflora (896.23 cm^2), King Kuroda (889.51 cm^2), Kuroda Improved (856.17 cm^2), Kuroda-35 (851.74 cm^2), Shidur (845.26 cm^2), whereas, the minimum leaf area was recorded in Shin Kuroda (798.28 cm^2) followed by New Kuroda (834.13 cm^2) and Kuroda (842.12 cm^2). Varietal effect significantly influenced leaf area (Thakur *et al.,* 2018). Furthermore, the experimental data demonstrated that as plant height increased, there was a corresponding increase in the number of leaves per plant. The findings of Ali *et al*. (2006) and Shoma *et al*. (2014) in carrot are quite similar to these results.

3.4. Root length

Significant effect of variety was observed on root length of carrot. King Kuroda (17.31 cm) and Kuroda (16.53 cm), New Kuroda (16.25 cm), Kuroda -35 (16.13 cm), BAU Gajor-5 (15.78 cm), Prima Agroflora (15.77 cm) and Pusaha Keshor (15.75 cm) generated the longest roots, in that order. In contrast, the Bankim Keshor yielded the shortest measurement, measuring (11.31 cm) (Table 2). Environmental and genetic factors strongly effect on root length. So, cultivars with a greater number of leaves have more root length (Choudhary *et al.,* 2023).

3.5. Root diameter

The largest root diameter measured, (3.46 cm) was from Kuroda. It was closely followed by Kuroda Improved (3.44 cm), King Kuroda (3.35 cm), New Kuroda (3.35 cm), Kuroda-35 (3.31 cm), and Pusha Keshor (3.32 cm), in that order. According to (Table 2), Bankim Keshor had the lowest root diameter (2.38 cm), followed by Bau Gajor-5 (2.39 cm), Pusha Keshor (2.44 cm) and Prima Agroflora (2.51 cm). Differences among root diameter might be due to genetic composition in the expression of growth potentials (Choudhary *et al.,* 2023). The similar variations in diameter of root among different varieties have reported by (Shoma *et al.,* 2014).

3.6. Individual root weight

Under drought stress, different varieties showed a substantial variance in the fresh weight of individual roots. (Table 2) shows that the King Kuroda variety had the maximum fresh weight of root (164.07 g), followed by Pusha Keshor (153.78 g), Kuroda -35 (153.23 g), Kuroda (153.51 g), and Bankim Keshor (151.34 g), in that order. BAU Gajor-5 produced the lowest fresh weight of each root (114.95 g), closely followed by Prima Agroflora (117.34 g). The fresh weight of the root may have increased due to increased root girth, diameter, and length. The fresh weight of the root was significantly impacted by the nutrient content (Kushwah *et al.,* 2019).

3.7. Root yield per plot

The highest root yield per plot (5.23 kg) was generated by King Kuroda (Table 2), which was followed by Kuroda-35 (4.70 kg), Kuroda (4.66 kg) and New Kuroda (4.52 kg). Prima Agroflora had the lowest root production per plot (1.99 kg), closely followed by BAU Gajor-5 (2.00 kg). So, the yield of roots per plot was significantly affected by the interaction effect of genotype (Shoma *et al.,* 2014).

3.8. Gross yield per hectare

The King Kuroda produced the highest gross yield of carrots (34.89 t ha^{-1}), which was followed by Pusha Keshor (32.84 t ha^{-1}), Kuroda-35 (31.39 t ha^{-1}), New Kuroda (30.14 t ha^{-1}), and Kuroda (31.06 t ha^{-1}), respectively While BAU Gajor-5 (13.37 t ha^{-1}) and Prima Agroflora (13.30 t ha^{-1}) obtained the lowest gross yield, respectively (Figure 1). (Biratu *et al.,* 2022) reported that the performances of carrot varieties are the combined effect of environmental factors (location) and the genotypic features of variety.

3.9. Marketable yield per hectare

There was a notable variation in the marketable yield of roots ton per hectare among the different varieties (Figure 2). Following King Kuroda (30.07 t ha^{-1}) in terms of marketable root yield, Kuroda-35 (28.59 t ha^{-1}), Pusha Keshor (26.94 t ha^{-1}), Shin Kuroda (26.60 t ha^{-1}), Kuroda (26.34 t ha^{-1}) and new Kuroda (26.07 t ha^{-1}) were the next greatest producers. BAU Gajor-5 produced the lowest commercial yield (11.67 t ha^{-1}), closely followed by Prima Agroflora (12.42 t ha^{-1}) (Figure 2).

Plate 2. Pictorial view of root length of different variety. V_1 = Kuroda, V_2 = New Kuroda, V_3 = Kuroda-35, V_4 = King Kuroda, V_5 = Shin Kuroda, V_6 = Kuroda Improved, V_7 = Shidur, V_8 = BAU Gajor-5, V_9 = Prima Agroflora, V_{10} = Bankim Keshor, V_{11} = Pusha Keshor

Table 1. Effects of varieties on plant height, number of leaves/plant, leaf area at different days after sowing

Variety	Plant height (cm) at different DAS				Number of leaves/plant at different DAS				Leaf area (cm^2) at different DAS			
	30	45	60	75	30	45	60	75	30	45	60	75
V_1	12.57	19.23	36.25	59.07	2.93	5.00	8.13	11.04	71.85	96.69	600.79	842.12
V_2	13.93	19.27	35.13	57.77	3.07	4.93	7.80	10.20	78.15	165.95	539.47	834.13
V_3	13.34	19.61	35.11	50.67	3.00	4.87	7.20	11.07	86.46	162.97	559.42	851.74
V_4	13.76	20.97	38.48	55.22	3.00	4.67	7.33	10.74	74.85	141.25	747.32	889.51
V_5	13.39	18.90	35.38	58.23	2.93	4.67	7.40	10.33	82.06	177.66	490.22	798.24
V_6	12.90	16.43	36.02	55.20	3.07	4.77	7.53	10.93	66.81	81.50	588.14	856.17
V_7	13.03	18.90	36.11	55.00	3.00	5.00	7.33	10.33	79.34	176.37	677.77	845.26
V_8	11.71	18.61	39.99	126.23	3.00	4.87	7.20	10.87	66.71	156.23	755.86	910.74
V_9	13.34	18.34	39.76	87.17	3.00	4.67	7.73	10.33	72.81	227.12	743.77	896.23
V_{10}	15.89	22.65	42.90	62.87	3.47	5.36	8.00	10.33	101.33	194.80	1113.15	1226.19
V_{11}	13.85	20.74	35.69	128.27	3.00	4.87	5.80	10.93	89.60	181.40	646.47	848.33
$LSD_{0.05}$	0.58	0.92	1.15	0.96	0.05	0.10	0.25	0.27	2.56	14.30	26.76	16.79
$LSD_{0.01}$	0.79	1.25	1.56	1.31	0.07	0.14	0.34	0.36	3.49	19.50	36.50	22.90
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability; V1 = Kuroda, V2 = New Kuroda, V3 = Kuroda-35, V4 = King Kuroda, V5 = Shin Kuroda, V6 = Kuroda Improved, V 7 = Shidur, V8 = BAU Gajor-5, V9 = Prima Agroflora, V10 = Bankim Keshor, V11 = Pusha Keshor

Table 2. Performance of varieties on yield, yield-contributing, and quality characters of carrot under drought stress

Variety	Root Length (cm)	Root diameter (cm)	Individual root yield ($g\ plant^{-1}$)	Root yield ($kg\ plot^{-1}$)	% Cracked root	% Branched root	% Rotten root	TSS (%)	Leave dry matter (%)	Root dry matter (%)
V_1	16.53	3.46	153.51	4.66	8.55	3.46	0.33	12.07	19.88	8.85
V_2	16.25	3.35	144.43	4.52	8.04	4.44	1.02	11.07	19.54	8.37
V_3	16.13	3.31	153.23	4.70	5.43	2.98	0.50	12.40	20.00	9.25
V_4	17.31	3.35	164.07	5.23	8.65	5.14	0.00	10.27	21.33	9.85
V_5	14.87	3.17	147.99	4.14	2.64	1.09	0.16	13.13	17.89	9.25
V_6	15.63	3.44	140.17	3.98	6.07	3.24	0.00	10.73	20.08	8.89
V_7	14.80	2.93	142.66	3.99	7.04	1.95	0.38	12.40	19.77	8.79
V_8	15.78	2.39	114.95	2.00	0.00	12.85	0.00	9.40	15.30	8.09
V_9	15.77	2.51	117.32	1.99	0.63	5.97	0.00	11.00	15.13	7.03
V_{10}	11.31	2.38	151.34	4.63	8.60	9.52	0.00	10.34	16.67	8.79
V_{11}	15.75	3.32	153.78	4.92	1.68	16.27	0.00	10.75	19.97	8.94
LSD 0.05	0.21	0.13	2.54	0.14	0.52	0.51	0.06	0.38	0.71	0.27
LSD 0.01	0.29	0.18	3.46	0.19	0.71	0.70	0.08	0.52	0.97	0.37
Sig. level	**	**	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability; V1= Kuroda; V2 = New Kuroda; V3= Kuroda-35; V4 = King Kuroda; V5 = Shin Kuroda; V6 = Kuroda Improved; V7 = Shidur; V8 = BAU Gajor-5; V9 = Prima Agroflora; V10 = Bankim Keshor; V11 = Pusha Keshor

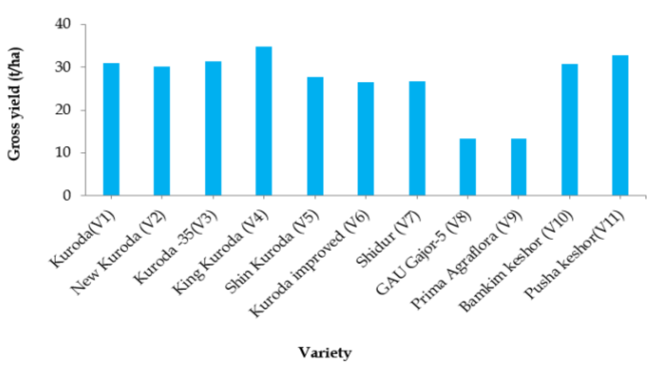

Figure 1. Effects of varieties on gross yield at different days after sowing. Vertical bar indicates LSD at 1% level of probability

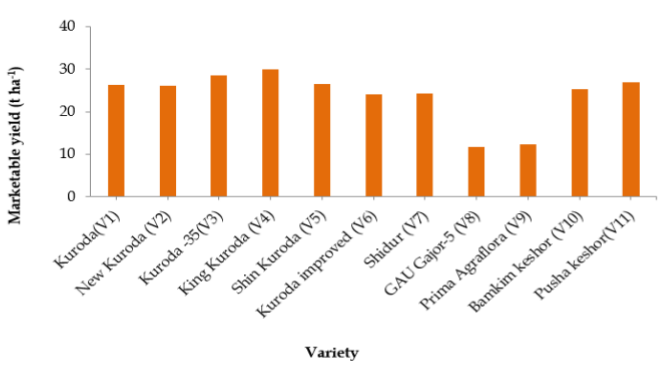

Figure 2. Effects of varieties on marketable yield at different days after sowing. Vertical bar indicates LSD at 1% level of probability

4. Conclusion

This study evaluated the performance of growth, yield, and quality of 11 carrot varieties under drought stress. According to the study, selecting the appropriate carrot variety would help to increase productivity in areas prone to drought. Therefore, it can be concluded that on the overall basis the best performing cultivars have been King Kuroda, Kuroda-35 and Pusha Keshor were found to be better in respect of growth, yield and quality of carrot under drought stress compared to other varieties. Maintaining and controlling optimum irrigation and water management in the experimental plot was a challenge in this research. Future research would be conducted with various watering regime and in different conditions for further recommendation for this research. However, the findings of this research could be used for practical implications for the carrot growers to select the drought tolerant variety and used in the water deficit areas or char lands in Bangladesh.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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