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CROP PRODUCTION

Effect of the planting season on carrot cultivars growth and yield in the brazilian semiarid region

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ABSTRACT. In regions with high temperatures, carrot cultivation is impracticable, as high temperatures tend to reduce yield and quality of the product. However, with the advent of summer cultivars, carrot cultivation in these regions has become viable. The aim of this work was to evaluate the performance of ten carrot cultivars in different planting seasons. The experiments were carried out at the Rafael Fernandes Experimental Farm of the Federal Rural Semiarid University (UFERSA). The experiments were carried out in May, June, July and August of 2017. The experimental design was a randomized block with ten treatments and four repetitions. The characteristics that were evaluated were the root classification (long, average and short roots); commercial, non-commercial and total yield; dry plant weight and root fresh weight. Both the planting season and the cultivar played important roles in agronomic performance throughout the experimental period. In May and June, the highest average yields and plant growth were obtained (43 and 45 t ha^{-1} yield, respectively). Hybrid cultivars showed better performance than open-pollinated cultivars in terms of yield. The Brasília, BRS Planalto, and Kuronan varieties showed poor performance in all the evaluated characteristics.

Keywords: *Daucus carota* L.; adaptability; performance; high temperatures.

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Introduction

Temperatures affect carrot crops throughout their life cycles. For fast and uniform germination, the ideal temperature range is from 20 to 30°C. In general, temperatures above 30°C may induce a shortened vegetative cycle, affecting root development and yield. Average temperatures between 10 and 15°C benefit root elongation and the development of the characteristic carrot colouring, while temperatures above 21°C induce the formation of short and poorly coloured roots (Vieira & Pessoa, 2008). Therefore, the ambient temperature is an important deciding factor in the choice of cultivar to be cultivated in different regions and climates (Seljasen et al., 2013).

To overcome the limitations imposed by high temperatures, Brazilian researchers have developed cultivars with good performance in the temperature range of 18 to 25°C. The new varieties show resistance to diseases caused by fungi and nematodes in addition to having good climate adaptability. This has made planting carrots in regions and states where temperatures are higher, such as Bahia and Goiás, possible (Silva, Vieira, & Nascimento, 2011). The use of summer cultivars and the use of seeds from the primary umbel has been the main strategy for enabling carrot cultivation in regions where this vegetable was not cultivated before (Resende et al., 2016; Nascimento, 2000).

Although the summer cultivar 'Brasília' is still one of the most widely used cultivars in warm regions during the summer, in recent years, the planted area using imported hybrids has also increased, and research using these new materials, mainly under high-temperature conditions, is still incipient. The advantages of hybrid cultivars over open-pollinated cultivars include a higher degree of hybrid heterosis and vigour (Groszmann, Greaves, Fujimoto, Peacock, & Dennis, 2013), as well as greater uniformity in the internal root colour and a low presence of white rings.

However, in some states, even with the advent of summer cultivars and hybrid cultivars, carrot production is insufficient to meet even domestic demand. For example, in Rio Grande do Norte, virtually all commercialized carrots come from Bahia, which increases the price of carrots on the local market (Bezerra Neto, Porto, Gomes, Cecílio Filho, & Moreira, 2012; Teófilo, Freitas, Negreiros, Lopes & Vieira, 2009).

The difficulties of carrot production in warm and lower-altitude regions require research, particularly in the selection of cultivars with genetic potential for quality root production under high temperatures.

Thus, it is assumed that the planting season, due to climatic and environmental variations such as precipitation, temperature, and cloudiness, influences the agronomic performance of carrot cultivars cultivated in the region of Mossoró, Rio Grande do Norte state.

The objective of this work was to evaluate the yield and quality of carrot cultivars in different planting seasons under the growing conditions in Mossoró, Rio Grande do Norte State.

Material and methods

Location and characterization of the study area

The experiments were carried out at Rafael Fernandes Experimental Farm, 20 km away from Mossoró (Rio Grande do Norte State) (Latitude 5°03'37” S; Longitude 37°23'50” W; average altitude 72 m), in a sandy loam Argissolic Red Latosol (Empresa Brasileira de Pesquisa Agropecuária [Embrapa], 2016). Four experiments were implemented, with plantings in May (season 1), June (season 2), July (season 3), and August (season 4) 2017.

The climate of the region according to the Köppen classification is BSwh', dry and very hot. There are two climatic seasons: a dry season, which usually covers the period from June to January, and a rainy season between February and May (Carmo Filho, Espínola Sobrinho, & Maia Neto, 1991). Table 1 shows the monthly averages for temperature, relative humidity, precipitation and solar radiation during the experimental period.

Table 1. Meteorological data for the study area during the experimental period.

Year	Month	Temperature (°C)			Air Relative Humidity (%)		
		Mean	Maximum	Minimum	Mean	Maximum	Minimum
2017	May	27.97	38.64	19.39	75.58	98.00	31.90
	June	27.72	36.31	20.65	70.79	97.30	31.50
	July	26.99	35.64	19.10	66.86	98.20	29.30
	August	27.45	37.92	19.37	64.94	93.50	29.00
	September	27.96	38.45	19.56	60.42	90.80	24.50
	October	28.32	38.64	21.03	64.19	91.40	29.30
	November	28.04	37.15	20.96	67.75	91.50	32.90
	December	28.40	37.29	21.84	69.19	93.50	36.70
2018	January	28.10	37.45	20.25	71.65	96.60	30.00
Year	Month	Rainfall (mm)			Solar Radiation (W m^{-2})		
2017	May	15.40			226.38		
	June	14.20			211.31		
	July	58.60			198.87		
	August	0.20			254.67		
	September	2.40			263.64		
	October	0.80			267.05		
	November	0.60			277.66		
	December	1.40			250.93		
2018	January	64.40			236.14		

For the chemical characterization of the soil, soil samples were collected from 0 to 20 cm depth. The results are presented in Table 2. As the experiments were implemented in adjacent areas, only a composite sample was taken from the experimental area for analysis.

Table 2. Chemical characterization of the soil in the experimental areas. Mossoro, Rio Grande do Norte State. Ufersa, 2017.

pH	EC	P[1]	K^+	Na^+	Ca^{2+}	Mg^{+2}
(água)	dS m^{-1}	--------------mg dm^{-3} ---------------			------Cmol$_c$ dm^{-3} ------	
5.10	0.03	6.70	32.20	4.80	0.80	0.50

[1]Melich Extractor 1.

Treatments and experimental design

The experimental design was in randomized blocks with 10 treatments and four replications. The treatments consisted of the cultivars Brasília (TopSeed®), BRS Planalto (ISLA®), Supreme (ISLA®), Native (Sakata®), Kuronan (ISLA®), Mariana (Feltrin®), Melinda (Feltrin®), Amanda, (Agristar®), Francine (Agristar®), and Erica (Agristar®), cultivated in May, June, July, and August. Each experimental plot consisted of a 3.0 x 1.0 m seedbed with six rows of plants spaced 0.15 x 0.06 m . The four central rows were considered the useful area, not including one plant at each end of the row.

Implementation and conduct of the experiment

The tillage consisted of ploughing, harrowing and raising the beds to a height of approximately 0.20 m. Fertilization was performed based on the soil analysis and on recommendations from carrot producers in the region, with adaptations made according to the needs of the crop. At each planting, 120 kg ha^{-1} of N, 460 kg ha^{-1} of P_2O_5 and 110 kg ha^{-1} of S were applied.

Fertilization was performed three times a week via fertigation from 15 to 90 days after germination, using 98.4 kg ha^{-1} N, 300 kg ha^{-1} P_2O_5, 170 kg ha^{-1} K_2O, 7.1 kg ha^{-1} Mg, 1 kg ha^{-1} Ca, 13.7 kg ha^{-1} SO^4, and 1.7 kg ha^{-1} B for each experiment. Micronutrients were supplied at a dosage of 1.6% K_2O, 1.28% S, 0.86% Mg, 2.1% B, 0.36% Cu, 2.66% Fe, 2.48% Mn, 0.036% Mo, and 3.38% Zn. A phytosanitary product was applied for the preventive control of gall nematodes.

Sowing was performed manually in the transverse direction of the bed in pits approximately 2.0 cm deep, with 3 to 4 seeds per pit. Thinning was performed 25 days after sowing (DAS), leaving one plant per hole.

The irrigation system used in the first 15 days after sowing was a microsprinkler. Drip irrigation was used during the remainder of the crop cycle. The drip irrigation was performed with three hoses per seedbed spaced 0.15 m apart and with drippers every 0.20 m. Irrigation was performed daily, and the irrigation depth was based on the crop evapotranspiration (Allen, Pereira, Raes, & Smith, 2006).

Harvesting was performed when the older leaves yellowed and dried and the younger leaves bent down, which occurred on average 120 days after sowing.

Characteristics evaluated

Root growth and production were evaluated.

Plant height (cm): Fifteen plants per plot were measured from the ground to the end of the highest leaf. The measurement was performed 80 days after planting.

Average number of leaves: Number of leaves of 15 plants in the useful area.

Root classification (%): Long (length 17 to 25 cm, diameter less than 5 cm), medium (length 12 to 17 cm, diameter greater than 2.5 cm), short (length 5 to 12 cm, diameter greater than 1 cm) and scrap (roots that did not fit the previous measurements or showed damage), according to Lana and Vieira (2000).

Commercial productivity (t ha^{-1}): The sum of the production of long, medium and short roots.

Non-commercial productivity (t ha^{-1}): The sum of the production of scrap roots and roots with cracks, bifurcations, nematodes and mechanical damage.

Total productivity (t ha^{-1}): The sum of commercial and non-commercial productivity.

Average root mass: Ten roots from the plot area were washed and weighed.

Total dry mass: Ten plants were collected from the plot, separated into tops and roots, washed, packed in paper bags and placed in a forced air circulation oven, with the temperature set at 65°C until reaching a constant mass.

Statistical analysis

A variance analysis of the evaluated characteristics was performed separately for each experiment. Then, the experiments were jointly analysed for those characteristics that passed the homogeneity test, according to Pimentel-Gomes (2009). The characteristics that did not demonstrate homogeneity were corrected according to the methodology recommended by Pimentel-Gomes (2009). Statistical analysis was carried out using SISVAR v 5.3 software (Ferreira, 2007). To compare the means, the Scott-Knott test at the 5% probability level was used.

Results and discussion

The average plant height ranged from 44.42 (Amanda) to 50.68 cm (BRS Planalto) (Table 3). The cultivars Nativa, BRS Planalto, Mariana and Kuronan were the tallest, and the cultivars Amanda, Brasília, Érica, Francine, Melinda, and Suprema were the shortest; within each group, the height results were statistically similar.

Regarding the planting season, the highest plant heights were observed in the cultivations carried out in May and June. This effect is possibly associated with the better climatic conditions for plant growth and development during these months (low rainfall, low irradiance and lower minimum temperatures).

Table 3. Plant height (PH), number of leaves per plant (NL), root dry matter (RDM), leaf dry matter (LDM) and total dry matter (TDM) of carrot cultivars as a function of the planting season. Mossoró, Rio Grande do Norte State. Ufersa, 2017.

Cultivars	PH (cm)	NL	RDM (g plant^{-1})	LDM (g plant^{-1})	TDM (g plant^{-1})
Amanda	44,42 b	9,6 b	13,91 a	10,73 b	24,65 a
Brasília	46,38 b	10,1 a	11,09 b	11,91 a	23,00 a
BRS Planalto	50,68 a	9,2 b	10,55 b	12,49 a	23,04 a
Érica	46,16 b	9,3 b	13,02 a	10,34 b	23,36 a
Francine	46,29 b	8,8 c	12,69a	10,06 b	22,75 a
Kuronan	47,68 a	9,8 a	10,54 b	13,15 a	23,69 a
Mariana	48,59 a	9,3 b	10,46b	11,17 b	21,63 a
Melinda	45,34 b	8,5 c	12,41 a	9,89 b	22,32 a
Nativa	50,68 a	8,0 c	13,44 a	8,72 b	22,16 a
Suprema	45,20 b	9,6 b	11,87 b	12,66 a	24,52 a
Planting Season	PH (cm)	NL	RDM (g plant^{-1})	LDM (g plant^{-1})	TDM (g plant^{-1})
May (Season 1)	49.46 a	9.20 a	12.83 a	10.48 c	23.31 a
June (Season 2)	50.58 a	9.14 a	13.27 a	9.58 c	22.86 a
July (Season 3)	40.81 c	9.47 a	12.10 a	11.44 b	23.54 a
August (Season 4)	47.54 b	9.11 a	9.54 b	13.15 a	22.69 a

Means followed by the same letter are not significantly different from each other according to the Scott-Knott test at 5% probability.

Brasília and Kuronan had a higher number of leaves per plant than the other cultivars and did not differ significantly from each other.

The hybrids Amanda, Érica, Francine, Melinda, and Nativa had the highest average root dry matter (Table 3). This was probably due to the greater resilience of hybrid cultivars to adverse weather conditions; these cultivars took advantage of the high amount of light radiation energy available during the experimental period to increase their root dry matter.

In terms of planting time, the average root dry matter from the August cultivation was significantly lower than that from the other seasons.

Leaf dry matter showed the opposite trend as root dry matter, with the open-pollinated cultivars (OP) having the highest averages, especially Kuronan and Suprema. The OP cultivars allocated most of their photoassimilates to the leaves; as a consequence, these cultivars showed a reduction in root dry matter. In turn, the plants with the highest height were also those with the highest accumulation of dry matter in the leaves. The August planting favoured higher average leaf dry matter than the other plantings, which is probably related to the high temperatures and high solar radiation during the development cycle of the plants cultivated in this month; these climate conditions impair root elongation and favour vegetative development (Vieira & Pessoa, 2008).

There was no significant difference in total dry matter among the cultivars or the growing seasons.

A significant interaction was observed between planting time and cultivar for the average root mass (Table 4). On average, this characteristic ranged from 80.4 g (Mariana) to 121.8 g (Amanda).

In the analysis of the cultivar x planting season interaction, it was observed that there was no significant difference in the average mass of the roots cultivated in May. For the three remaining planting seasons, two groups of cultivars formed, and Amanda and Nativa had the highest average root mass. In general, hybrids showed better performance than open-pollinated cultivars, which is to be expected; hybrids have a higher degree of heterosis and hybrid vigour, which ensures their greater adaptability to adverse climatic conditions.

In the municipality of Mossoró, Rio Grande do Norte State, Brazil, Lopes et al. (2008) obtained an average commercial root mass of 58.84 g for the cultivar Brasília. The averages found by those authors are lower than those found here, which is probably related to the harvest period chosen by those authors (79 DAS) as well as their irrigation and fertilization management practices (micro-sprinklers and granulated fertilizers applied directly to the seed beds).

Table 4. Average root mass (g) of carrots as a function of the planting season. Mossoró, Rio Grande do Norte State. Ufersa, 2017.

Cultivars	Planting Season				
	May (Season 1)	June (Season 2)	July (Season 3)	August (Season 4)	Mean
Amanda	119.0 aA	133.7 aA	120.1 aA	114.2 aA	121.75
Brasília	102.0 aA	101.4 bA	77.2 bB	65.5 bB	86.53
BRS Planalto	92.2 aA	86.8 bA	100.5 aA	77.3 bA	89.20
Érica	110.5 aA	117.6 aA	111.6 aA	78.0 bA	110.52
Francine	100.4 aB	125.2 aA	85.4 bB	95.6 aB	101.65
Kuronan	99.8 aA	100.5 bA	75.7 bB	60.2 bB	84.05
Mariana	94.9 aA	74.9 bA	81.6 bA	70.2 bA	80.40
Melinda	122.5 aB	87.1 bA	117.5 aB	89.8 aA	104.23
Nativa	90.5 aA	117.1 aA	119.4 aA	113.4 aA	110.11
Suprema	115.1 aA	109.7 aA	88.4 bB	66.6 bB	94.94
Mean	104.7	105.4	97.7	83.5	

Means followed by the same letter, uppercase in the rows and lowercase in the columns, are not significantly different according to the Scott-Knott test at 5% probability.

In terms of the classification of the roots, a significant interaction was observed between cultivar and planting season for long, medium and scrap root yields (Table 5). Long roots were produced in smaller quantities in all four growing seasons, while medium roots were the most common.

During May and June, there was no statistically significant difference in the percentage of long roots among cultivars. In July and August, a significant difference was observed among the cultivars. In July, the group with the highest mean long root percentage was composed of the cultivars Amanda, Érica, Melinda, and Suprema; in August, this group was composed of the cultivars Amanda, BRS Planalto, Erica, Francine, Melinda, Nativa, and Suprema (Table 5).

The hybrid cultivars Amanda, Érica, Francine, and Melinda and the open-pollinated cultivars BRS Planalto and Suprema achieved the highest percentages of long roots in all planting seasons. The planting in August resulted in the highest percentage of long root production. This probably occurred because of the late growth cycle of the plants sown in August (plants were not ready for harvest until 150 DAS), which could have allowed more root elongation (Table 5).

In terms of medium roots, no significant difference was observed between cultivars only in Season 1. The cultivars with the highest medium root percentage were the hybrids Amanda, Érica, Francine, Mariana, Melinda, and Nativa. Among the open-pollinated cultivars, only Suprema stood out. Even so, the cultivar Suprema presented a medium root percentage that was lower than that of all hybrids studied in the experiment.

The planting carried out in May resulted in the highest percentage of medium roots, while the planting carried out in July had the lowest percentage of medium roots (Table 5).

In the analysis of the cultivar x planting season interaction, it was observed that the cultivars Amanda, Érica, Francine, Kuronan, Mariana, Melinda, and Suprema did not show significant differences among the seasons; therefore, these cultivars were able to maintain a constant medium root percentage during all four seasons.

The Brasília cultivar, however, showed a gradual decrease in the percentage of medium roots between planting seasons 1 and 4. Similar behaviour was observed in the BRS Planalto cultivar. This decrease is probably related to the interaction of the genotype with the local climate, as the OP cultivars obtained higher medium root percentages during planting seasons 1 and 2. During planting seasons 1 and 2, the crop production cycle took place during months with milder minimum temperatures and lower solar radiation, which would have favoured root elongation in the OP cultivars, resulting in a higher percentage of medium roots. The percentage of medium roots in the hybrid cultivars did not vary significantly during the planting seasons (except in the Nativa cultivar), which indicates the lower susceptibility of hybrid cultivars than of OP cultivars to climate shifts.

In Mossoró, Rio Grande do Norte State, Brazil, Lopes et al. (2008) obtained average medium root percentages ranging from 33.01 (Esplanada) to 59.34% (Brasília).

Regarding the scrap root percentage, during Season 1, there was no significant difference in the percentage of non-commercial roots among cultivars (Table 5). On average, for all planting seasons, the cultivars that produced the largest amount of non-commercial roots were Brasília and BRS Planalto. The other cultivar percentages ranged from 17.31% (Melinda) to 26.40% (Kuronan). The planting in May resulted in the lowest percentage of non-commercial roots, while season 3 had the highest average of percentage of scrap roots.

Table 5. Percentages of long, medium and scrap roots of carrot cultivars as a function of different planting seasons. Mossoró, Rio Grande do Norte State. Ufersa, 2017.

Cultivars	Long Roots (%)				
	Planting Season				
	May (Season 1)	June (Season 2)	July (Season 3)	August (Season 4)	Mean
Amanda	9.31 aA	7.95 aA	17.19 aA	11.25 aA	11.43
Brasília	10.30 aA	7.12 aA	2.36 bA	4.75 aA	6.13
BRS Planalto	16.38 aA	12.54 aA	4.23 bB	14.19 aA	11.83
Érica	13.63 aA	13.73 aA	17.68 aA	25.00 aA	15.78
Francine	7.47 aA	7.03 aA	9.05 bA	15.89 aA	9.86
Kuronan	3.39 aA	1.49 aA	1.97 bA	3.40 bA	2.56
Mariana	6.85 aA	1.79 aA	8.47 bA	4.09 bA	5.30
Melinda	10.24 aB	7.85 aB	23.17 aA	12.69 aB	13.49
Nativa	1.38 aB	4.67 aB	9.72 bA	12.52 aA	7.07
Suprema	7.99 aA	7.20 aA	12.77 aA	15.13 aA	10.78
Mean	8.69	7.14	10.66	10.83	
	Medium Roots (%)				
Cultivars	Planting Season				
	May (Season 1)	June (Season 2)	July (Season 3)	August (Season 4)	Mean
Amanda	51.76 aA	41.45 aA	41.99 aA	54.96 aA	47.54
Brasília	43.93 aA	35.67 bA	26.78 bB	24.69 bB	32.77
BRS Planalto	53.42 aA	35.10 bB	22.56 bB	40.74 bA	37.96
Érica	50.87 aA	46.76 aA	48.52 aA	64.29 aA	49.91
Francine	41.64 aA	48.17 aA	47.99 aA	54.85 aA	48.17
Kuronan	38.94 aA	27.10 bA	25.57 bA	35.62 bA	31.81
Mariana	45.46 aA	47.37 aA	41.22 aA	52.54 aA	46.65
Melinda	61.78 aA	55.37 aA	46.07 aA	51.90 aA	53.78
Nativa	45.44 aB	47.41 aB	33.91 bB	61.31 aA	47.02
Suprema	45.45 aA	45.09 aA	51.21 aA	44.35 bA	46.53
Mean	47.87	42.95	38.58	47.25	
	Scrap Roots (%)				
Cultivars	Planting Season				
	May (Season 1)	June (Season 2)	July (Season 3)	August (Season 4)	Mean
Amanda	15.89 aA	25.92 bA	22.27 bA	14.38 bA	19.62
Brasília	25.37 aB	31.06 aB	46.53 aA	47.88 aA	37.71
BRS Planalto	15.43 aB	38.79 aB	60.04 aA	24.81 bB	34.77
Érica	13.72 aA	21.49 bA	21.62 bA	16.60 bA	18.04
Francine	20.54 aA	23.35 bA	28.73 bA	7.14 bA	22.31
Kuronan	22.44 aA	27.75 bA	34.91 bA	20.50 bA	26.41
Mariana	11.41 aA	19.89 bA	25.00 bA	15.18 bA	17.87
Melinda	11.49 aA	18.64 bA	21.80 bA	17.28 bA	17.31
Nativa	23.15 aA	22.90 bA	27.37 bA	12.26 bA	21.42
Suprema	16.47 aA	24.45 bA	14.53 bA	21.92 bA	19.35
Mean	17.6	25.43	30.28	20.83	

Means followed by the same letter, uppercase in the rows and lowercase in the columns, are not significantly different according to the Scott-Knott test at 5% probability.

In the analysis of the cultivar x planting season interaction, only the cultivars Brasília and BRS Planalto showed significant variation in their percentages of scrap roots among planting seasons, and these values were higher in July and August.

The high percentage of non-commercial roots in the cultivation that began in July may be related to the precipitation observed in that month (58.60 mm) as well as the monthly increases in solar irradiance during the crop cycle.

Among the hybrid cultivars, Francine had the highest percentage of non-commercial roots. The cultivar BRS Planalto, in Season 3, produced 60.04% scrap roots, and the cultivar Brasília, in seasons 3 and 4, yielded up to 50% scrap roots. These cultivars, in addition to having a large number of deformed roots, were susceptible to the attack of gall nematodes (*Meloidogyne* spp.), especially in seasons 3 and 4. During these planting seasons, Brasília also showed intense root discoloration that rendered the roots unmarketable.

For cultivar Brasília grown in Mossoró, Rio Grande do Norte State, Brazil, Lopes et al. (2008) reported that the average percentage of non-commercial roots was 18.78%.

For the percentage of short roots and the commercial, non-commercial and total yields, there were no significant interactions between the cultivar and the planting time (Table 6).

Table 6. Short root percentage (SR); commercial yield (CY); non-commercial yield (NCY); and total yield (TY). Mossoró, RN. Ufersa, 2017.

Cultivars	SR (%)	CY (t ha^{-1})	NCY (t ha^{-1})	TY (t ha^{-1})
Amanda	21.41 c	32.50 b	8.10 b	46.10 a
Brasília	23.38 c	24.11 d	14.05 a	35.88 c
BRS Planalto	15.43 d	25.95 d	13.29 a	37.47 b
Érica	16.26 d	34.86 a	7.58 b	47.43 a
Francine	19.66 c	30.42 b	8.78 b	40.16 b
Kuronan	39.22 a	28.62 c	10.17 b	32.83 c
Mariana	30.17 b	31.59 b	6.90 b	35.51 c
Melinda	15.42 d	34.23 a	6.94 b	46.20 a
Nativa	24.48 c	31.84 b	8.94 b	47.55 a
Suprema	23.34 c	31.13 b	7.64 b	36.47 c
Planting Season	SR (%)	CY (t ha^{-1})	NCY (t ha^{-1})	TY (t ha^{-1})
May (Season 1)	25.84 a	35.38 a	7.60 c	43.00 a
June (Season 2)	24.48 a	35.99 a	12.27 a	44.91 a
July (Season 3)	20.47 b	22.60 c	9.81 b	37.43 b
August (Season 4)	21.10 b	27.58 b	7.25 c	36.07 b

Means followed by the same letter, uppercase in the rows and lowercase in the columns, are not significantly different according to the Scott-Knott test at 5% probability.

The cultivars Kuronan and Mariana produced the highest percentages of short roots (Table 6). The cultivars that produced lower percentages of short roots were BRS Planalto, Érica and Melinda. The cultivar Brasília produced a mean of 23.38% short roots, similar to the value found by Lopes et al. (2008).

The hybrid cultivars Érica and Melinda showed the highest commercial yields. The higher degree of heterosis and hybrid vigour are responsible for the better performance of the hybrid cultivars compared to that of the OP cultivars in terms of commercial productivity. In addition, the hybrid cultivars appeared to be resistant to gall nematode disease. Among the OP cultivars, Suprema stood out, with a commercial yield of 31.13 t ha^{-1} (Table 6).

The highest commercial yields were obtained from the cultivation periods beginning in May and June, likely due to the milder daily minimum temperatures and lower solar radiation during this period.

The cultivars Brasília and BRS Planalto presented the highest mean non-commercial yields, while the yields of the remaining cultivars did not differ significantly from each other (Table 6).

The planting seasons with the lowest non-commercial yields were season 1 and season 4. Season 2 showed the highest non-commercial yield, although it also achieved the highest total and commercial yield. The possible reason for the increase in non-commercial productivity in season 2 may be related to the rainfall observed in July, which would have impacted the initial development of the plants, affecting their entire development cycle.

The hybrids Amanda, Érica, Melinda, and Nativa had the highest total yields (Table 6). Among the open-pollinated cultivars, the highest total yield was obtained by the cultivar BRS Planalto.

The cultivation cycles begun in May and June resulted in the highest total yields. Crop cycles that began in the warmer months resulted in higher yields. It can be inferred that the milder minimum temperatures during this period may have influenced root growth.

For the state of Paraná, Paulus et al. (2012) obtained a total yield of 20 t ha^{-1} for Brasília and 18.3 t ha^{-1} for Kuronan.

Conclusion

The interaction between the carrot cultivar and the planting time had a significant influence on the agronomic performance of the studied cultivars for practically all evaluated traits.

The most appropriate months for planting carrots in the Brazilian semi-arid region are May and June. The cultivars Amanda and Melinda are the most suitable for planting in May, while Melinda, Suprema and Amanda are most suitable for planting in June, July and August, respectively.

The highest yields were achieved by the cultivars Amanda, Melinda, Nativa and Érica.

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