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RESEARCH ARTICLE

Early garlic as an alternative for planting in low-altitude regions in the semi-arid region

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ABSTRACT

Early garlic (*Allium sativum* L.) cultivars are an alternative for growing this vegetable in low-altitude semi-arid regions, due to its lower requirement for mild temperatures and photoperiod. However, it is necessary to identify the cultivars that best adapt to these environmental conditions to improve management and maximize their production characteristics. In this sense, the objective was to evaluate early garlic cultivars' biometric, yield, and quality characteristics under low altitude conditions in the semi-arid region. Two field trials were carried out in a Brazilian semi-arid region to evaluate 14 early-cycle and virus-free garlic cultivars. The climatic variations between the experiments influenced the performance of some cultivars in terms of biometric, yield, and quality characteristics. 'Inhumas Casca Roxa' (65.25 and 57.62 cm; 6.49 and 6.48 t in 2022 and 2023, respectively) and 'Ugarte' (61.70 and 55.14 cm; 6.34 and 5.62 t in 2022 and 2023, respectively) showed higher height and total yield. Likewise, 'Inhumas Casca Roxa' and 'Ugarte' stood out for bulb mass (20.00 and 19.61 g respectively), and percentage of bulbs in classes 5 (30.6% and 32.8%, respectively) and 6 (8.3% and 9.2%). These materials also showed good post-harvest quality characteristics, such as high pungency for fresh consumption and/or processing by industry. It is recommended to cultivate 'Inhumas Casca Roxa' and 'Ugarte' for garlic production in low-altitude semi-arid conditions.

Key words: *Allium sativum*, climate changes, pungency, quality, yield.

INTRODUCTION

Climatic factors are determinants for garlic (*Allium sativum* L.) development. This vegetable, originally from mild climate regions of Central Asia, requires low temperatures for full development (Pereira et al., 2021). However, due to climate change occurring around the world, it is essential to know the adaptability of crops to limiting environmental conditions (Sánchez-Virosta et al., 2021), which is why it is necessary to explore new agricultural areas for garlic cultivation.

Semi-arid regions have low rainfall and, in some areas, high temperatures and a photoperiod of around 12 h (Li et al., 2020), such as those that occur in the Brazilian Northeast region. Despite that, there are microregions at higher altitudes in which it is possible to grow mid- and late-cycle garlic cultivars (Morais et al., 2023). However, this geographical characteristic corresponds to small areas of the semi-arid region, limiting the production spaces for this vegetable.

Using virus-free early garlic cultivars is an alternative for cultivation in low-altitude conditions. This is due to the lower requirements of these materials in terms of temperature and photoperiod (Luís et al., 2020; Nassur et al., 2020; Lima et al., 2020; Almeida et al., 2022). The same authors highlight the adaptation of 'Branco

Mossoró', 'Canela de Ema', and 'Centralina' to semi-arid conditions, recommending the use of mulch to obtain a greater quantity of class 4, 5, and 6 bulbs. Also in these conditions, it is known that the foliar application of Si promotes an increase in height, dry mass, and yield of garlic 'Cateto Roxo' (Oliveira et al., 2024).

Another advance in garlic production is related to the clonal cleaning treatment of virus-infected garlic cultivars, which has demonstrated considerable gains in yield and quality when compared to infected materials, being one of the main advances in garlic cultivation (Nassur et al., 2020; Lima et al., 2020; Almeida et al., 2022; Sopha et al., 2024).

Despite the results already described in the literature, identifying more materials with good production characteristics and post-harvest quality is essential to advance the exploitation of early garlic under these environmental conditions. From this knowledge, it is possible to optimize its production capacity by improving agronomic management. Therefore, this research aims to evaluate early garlic cultivars' biometric, yield, and quality characteristics under low altitude conditions in the semi-arid region.

MATERIALS AND METHODS

Location and characterization of the experimental area

The experiments were carried out at the Rafael Fernandes Experimental Farm Brazil (5°03'27.1" S, 37°23'51.4" W; 83 m a.s.l.), Mossoró, Rio Grande do Norte, Brazil, from May to August 2022 and 2023. The region's climate is BSh type, according to Köppen. During experimental conduction, the area had a temperature, relative humidity, and average rainfall in 2022 of 25.9 °C, 81.6%, and 336.6 mm, respectively, while in 2023 the average data in this sequence were 27.3 °C, 75.7%, and 85.6 mm (Figure 1).

The soil of the experimental area is classified as Ultisol (Soil Taxonomy, 2014), equivalent to Argissolo in the Brazilian Soil Classification System (Santos et al., 2018). The characterization of the soil's chemical attributes in the two experiments is described in Table 1.

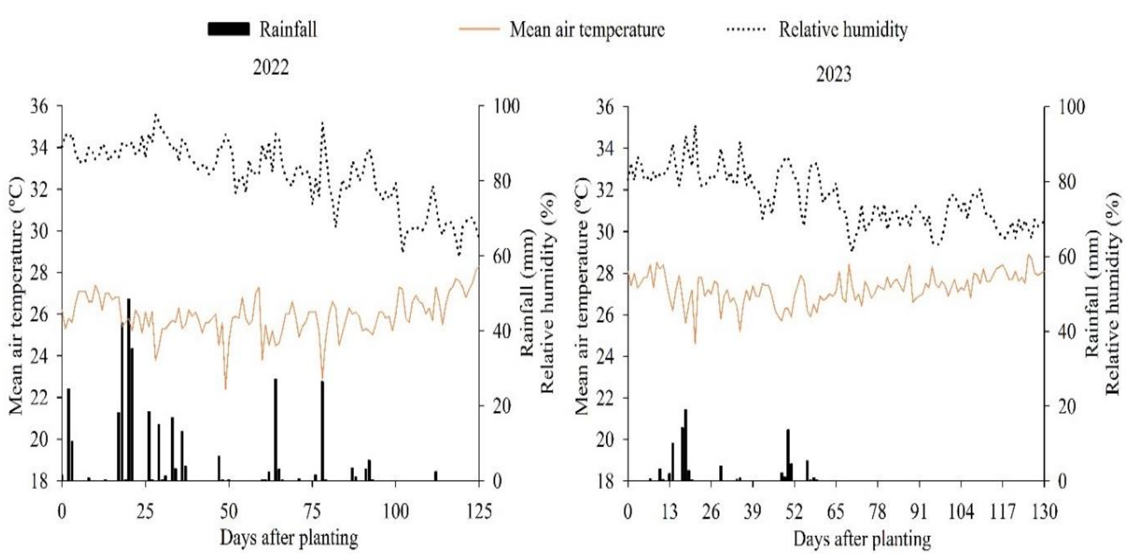

Figure 1. Mean air temperature, relative humidity, and rainfall in Mossoró, Brazil. 2024.

Table 1. Soil chemical analysis (0 to 20 cm depth) from experimental areas on the Rafael Fernandes Experimental Farm, in Mossoró, Brazil, in 2022 and 2023. 2024. EC: Electrical conductivity; OM: organic matter. P, K^+ and Na^+: Mehlich ($HCl+H_2SO_4$); Ca^{2+}, Mg^{2+} and Al^{3+}: KCl 1M. *S: $Ca(H_2PO_4)$.

Year	P	K^+	Ca^{2+}	Mg^{2+}	Na^+	S^*	H+Al	Al^{3+}
	mg dm^{-3}	cmol$_c$ dm^{-3}						
2022	8.40	0.12	1.25	0.64	0.01	2.01	0.70	0.00
2023	10.20	0.08	1.04	0.38	0.01	1.50	0.61	0.00
	pH	EC	OM	Cu	Fe	Mn	Zn	B
	H_2O	dS m^{-1}	g kg^{-1}	mg dm^{-3}				
2022	6.18	0.15	8.50	0.26	69.70	15.80	1.30	0.23
2023	6.12	0.11	7.90	0.24	61.40	15.10	1.60	0.20

Design, treatments, and experimental unit

The experimental design was randomized blocks, containing 14 treatments with four replicates. The experimental unit was 1.80 m^2 of bed, containing six rows of plants, spaced 0.2 × 0.1 m, totaling 90 plants per plot. The four central rows of plants were considered, disregarding those at the ends (1.04 m^2), for plant collection for analysis. The treatments consisted of garlic (*Allium sativum* L.) 'Branco Mineiro Casca Branca', 'Branco Mineiro CE', 'Branco Mineiro CSJ', 'Branco Mineiro Ijuí', 'Branco Mineiro PI', 'Canela de Ema', 'Cateto Roxo', 'Centralina A', 'Inhumas Casca Roxa', 'Inhumas E', 'Jundiaí', 'Novo Cruzeiro', 'Pinheiral' and 'Ugarte'.

In the 2022 trial, the virus-free garlic seed cloves used in vegetative propagation were provided by the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA - Hortaliças). In 2023, the garlic seed cloves produced in the 2022 trial were used, being selected according to the size of the bulbs and the absence of pests and diseases.

Installation and conduction of experiments

Soil preparation consisted of one plowing and two cross harrows at an average depth of 0.2 m, followed by the survey of beds with 0.3 cm height and 1.2 m width. Fertilization was carried out according to soil analyses (Table 1), and fertilization recommendations for garlic crops (Holanda et al., 2017).

Foundation fertilization consisted of 180 kg ha^{-1} P_2O_5, 163 kg ha^{-1} Ca and 112 kg ha^{-1} S using simple superphosphate (18% P_2O_5, 16% Ca and 11% S), and 17.5 t ha^{-1} organic compost based on cattle and goat manure (0.5% N, 0.3% P_2O_5 and 0.3% K_2O). Topdressing was carried out via fertigation starting at 20 until 105 d after planting (DAP), with a total application of 90 kg ha^{-1} N, 65 kg ha^{-1} K_2O, 50 kg ha^{-1} Ca, 22 kg ha^{-1} Mg, 20.0 kg ha^{-1} S, 2.1 kg ha^{-1} B, 2.1 kg ha^{-1} Cu, 16 kg ha^{-1} Fe, 13.6 kg ha^{-1} Zn and 14 kg ha^{-1} Mn applied in weekly split applications. Daily irrigation depths were carried out according to weather conditions and plant needs, with the application of 231.21 mm in 2022 and 379.87 mm in 2023 (Marouelli et al., 2015).

Phytosanitary control was carried out with products based on mancozeb and chlorfenapyr for the control of Trips (*Thrips tabaci*), imidacloprid and beta-cyfluthrin (Connect, Bayer, Dormagen, North Rhine-Westphalia, Germany), and copper hydroxide for the control of *Alternaria porri*. Weed control was carried out by hand, with the removal of spontaneous plants as needed.

Harvest

The harvest was carried out when the plants reached two-thirds of yellowish or dry leaves, at which time the bulbs were physiologically mature, with no damage to conservation after harvest. Then, curing was carried out in the field for 3 d, consisting of exposure to the sun with the leaves covering the bulbs and then curing in a shaded and ventilated place for 17 d.

'Branco Mineiro' (Casca Branca, CE, CSJ, Ijuí, and PI), 'Canela de Ema', 'Centralina A', 'Inhumas Casca Roxa', 'Inhumas E', 'Novo Cruzeiro', 'Pinheiral', and 'Ugarte' were harvested at 120 DAP in 2022 and at 115 DAP in 2023. 'Cateto Roxo' and 'Jundiaí' reached the harvest point at 125 DAP in 2022 and 130 DAP in 2023.

Characteristics evaluated

At 85 DAP, plant height (PH) and number of leaves (NL) were determined, measuring from ground level to maximum leaf length and the count of photosynthetically active leaves, respectively. After harvesting and curing, the percentage of sprouted plants (SP) was determined by the ratio between the number of sprouted plants and the number of plants harvested from the area considered for data collection.

Bulb mass (BM) was the average mass of marketable graded bulbs. The number of cloves per bulb (NCB), was obtained by counting cloves from differentiated bulbs. Total yield (TY) was estimated by weighing the bulbs of each plot, after the complete curing process. Marketable yield (MY) was estimated considering the mass of commercial bulbs.

The bulb classification (BC) was obtained through the transverse diameter, considering the percentage of unmarketable bulbs with a diameter < 32 mm or with sprouting with the total number of plants harvested in the area of data collection. As the percentage of marketable bulbs, class 3 (> 32 to 37 mm), class 4 (> 37 to 42 mm), class 5 (> 42 to 47 mm), and class 6 (> 47 to 56 mm) bulbs were considered to the number of plants harvested in the area considered for data collection.

Marketable class bulbs were used for bulb quality analysis, totaling six bulbs per experimental plot to determine soluble solids and pungency. Soluble solids (SS) were obtained directly from homogenized garlic juice, filtered through fait fabric, 100% polyester, by reading on a digital refractometer (model DBR 45, Zhejiang, Republic of China) with automatic temperature compensation, and the results were expressed in % (Horwitz and Latimer, 2011). The pungency (PUNG) was determined by the pyruvic acid content according to the colorimeter method (Schwimmer and Weston, 1961) and expressed in µmol pyruvic acid mL^{-1}.

The total solids (TS) were obtained by drying the cloves in a forced air circulation oven at 65 °C until they reached a constant mass. Then, the values were calculated by the difference between 100 and the moisture content of the cloves, and the results were expressed in g total solids 100 g^{-1} garlic (%) (IAL, 2005). The industrial index (II) was determined by the following formula: (Total solids × pyruvic acid)/100) (Carvalho et al., 1991).

Statistical analyses

The experimental data were subjected to ANOVA using the F test ($p < 0.05$). Then, the homogeneity of variance was verified between the years of cultivation, and a joint variance analysis was carried out (Pimentel-Gomes, 2009). For the cultivar factor, the means were grouped by the Scott-Knott test ($p < 0.05$), using the F test ($p < 0.05$) for significance between the years of cultivation through the SISVAR software version 5.6 (Ferreira, 2019).

RESULTS

Biometrics and yield

The interaction of cultivar and the years of experimental conduction influenced garlic growth and yield characteristics. The plant's height ranged between 48.95 and 65.25 cm in 2022, and 46.85 and 57.62 cm in 2023, with the highest average in 'Inhumas Casca Roxa' in both years. The number of leaves in this cultivar was statistically equal to the cultivars that presented higher averages for this variable (Table 2).

'Cateto Roxo and 'Jundiaí' did not show sprouted plants. For 'Novo Cruzeiro', in 2022, there was a higher percentage of sprouted plants (19.38%), while, in the following year, the sprouting was greater in 'Inhumas Casca Roxa' (9.67%) (Table 2).

For bulb mass, 'Inhumas Casca Roxa' and 'Ugarte' were superior to the others, with an average mass of 20.00 and 19.61 g $bulb^{-1}$, respectively. Regarding the years of cultivation, the highest bulb mass with an average of 16.14 g $bulb^{-1}$ was observed in 2023 (Figure 2).

The average number of cloves per bulb varied depending on the cultivar so that, for 'Branco Mineiro Ijuí', 'Canela de Ema', 'Inhumas Casca Roxa', 'Pinheiral', and 'Ugarte', there was also a difference between the experiments, increasing the number of cloves. 'Cateto Roxo' bulbs had the lowest number of cloves in both experiments (3.79 and 4.38, respectively), while in 'Centralina A' (16.67) and 'Canela de Ema' (21.42) there were higher averages in 2022 and 2023, in this sequence (Table 3). Bulb mass ranged from 12.3 to 20.0 g, with the superiority of 'Inhumas Casca Roxa' (20.0 g) and 'Ugarte' (19.61 g) (Figure 2).

The marketable yield of garlic bulbs ranged from 1.75 to 5.68 t ha^{-1} and 1.61 to 5.45 t ha^{-1} in 2022 and 2023, respectively. The lowest yields were observed in 'Cateto Roxo' (2022) and 'Jundiaí' (2023), while, in the first year, the marketable yield of bulbs was higher in 'Ugarte' and, in the next, in 'Inhumas Casca Roxa', which also stood out in 2022 with a yield of 5.36 t ha^{-1}. As for total bulb yield, lower yields were found in 'Cateto Roxo' (3.20 t ha^{-1}) and 'Jundiaí' (3.36 t ha^{-1}) compared to the other cultivars in 2022 and 2023', respectively, while in 'Inhumas Casca Roxa', there was a higher total yield of bulbs, with 6.49 and 6.48 t ha^{-1} for the first and second experiments (Table 3).

Table 2. Mean values of plant height, number of leaves, sprouted plants of early garlic cultivars. 2024. Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other by the Scott-Knott test ($p < 0.05$) and the F test ($p < 0.05$), respectively.

Cultivars	Plant height		Number of leaves		Sprouted plants	
	2022	2023	2022	2023	2022	2023
	cm		Leaf plant^{-1}		%	
Branco Mineiro Casca Branca	57.79^{cA}	53.22^{aB}	8.13^{aB}	8.75^{aA}	2.50^{cA}	0.76^{bA}
Branco Mineiro CE	58.10^{cA}	52.68^{aB}	8.92^{aA}	8.79^{aA}	3.13^{cA}	2.86^{bA}
Branco Mineiro CSJ	48.95^{eA}	50.08^{bA}	7.75^{bB}	8.58^{aA}	5.63^{bA}	4.75^{aA}
Branco Mineiro Ijuí	53.87^{dA}	51.39^{bA}	8.63^{aA}	8.79^{aA}	1.25^{cA}	0.58^{bA}
Branco Mineiro PI	54.16^{dA}	51.39^{bA}	7.63^{bB}	8.50^{aA}	3.75^{cA}	7.05^{aA}
Canela de Ema	54.44^{dA}	54.66^{aA}	7.56^{bA}	8.13^{aA}	2.50^{cA}	3.07^{bA}
Cateto Roxo	46.95^{eA}	46.85^{bA}	8.83^{aA}	8.21^{aB}	0.00^{cA}	0.00^{bA}
Centralina A	55.05^{dA}	50.77^{bB}	8.00^{bA}	7.96^{bA}	5.83^{bA}	6.46^{aA}
Inhumas Casca Roxa	65.25^{aA}	57.62^{aB}	8.54^{aA}	8.62^{aA}	6.25^{bA}	9.67^{aA}
Inhumas E	53.04^{dA}	49.81^{bA}	7.46^{bA}	7.62^{bA}	6.88^{bA}	4.52^{aA}
Jundiaí	56.91^{cA}	55.17^{aA}	7.08^{cA}	6.96^{cA}	0.00^{cA}	0.00^{bA}
Novo Cruzeiro	58.24^{cA}	55.87^{aA}	7.00^{cA}	7.25^{cA}	19.38^{aA}	2.81^{bB}
Pinheiral	60.91^{bA}	53.31^{aB}	8.71^{aA}	8.58^{aA}	8.75^{bA}	8.11^{aA}
Ugarte	61.70^{bA}	55.14^{aB}	8.71^{aA}	9.08^{aA}	4.38^{bA}	0.64^{bA}
Mean	56.10	52.71	8.07	8.27	5.02	3.66
CV, %	4.77		5.21		90.45	

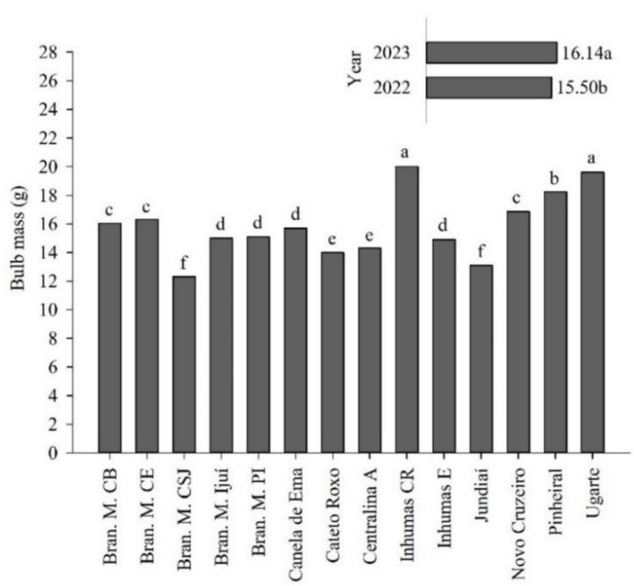

Figure 2. Bulb mass of early garlic cultivars. 2024. Means followed by the same letter do not differ from each other by the Scott-Knott test at ($p < 0.05$).

Table 3. Mean values of cloves per bulb, marketable yield, and total yield of early garlic cultivars. 2024. Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other by the Scott-Knott test ($p < 0.05$) and the F test ($p < 0.05$), respectively.

Cultivars	Cloves per bulb		Marketable yield		Total yield	
	2022	2023	2022	2023	2022	2023
	cloves $bulb^{-1}$		t ha^{-1}		t ha^{-1}	
Branco Mineiro Casca Branca	13.25^{bA}	13.04^{dA}	3.77^{bA}	4.25^{aA}	4.65^{cA}	5.11^{cA}
Branco Mineiro CE	12.38^{bA}	13.08^{dA}	4.98^{aA}	3.51^{bB}	5.47^{bA}	4.94^{cA}
Branco Mineiro CSJ	11.21^{cA}	11.37^{dA}	1.97^{dA}	2.85^{bA}	3.38^{dB}	4.23^{dA}
Branco Mineiro Ijuí	10.29^{cB}	14.50^{cA}	3.66^{bA}	3.86^{aA}	4.96^{bA}	4.68^{cA}
Branco Mineiro PI	14.54^{aA}	13.04^{dA}	3.30^{cA}	4.02^{aA}	4.17^{cB}	4.99^{cA}
Canela de Ema	15.50^{aB}	21.42^{aA}	3.57^{bA}	4.48^{aA}	4.55^{cB}	5.25^{bA}
Cateto Roxo	3.79^{dA}	4.38^{fA}	1.75^{dA}	2.48^{cA}	3.20^{dB}	4.10^{dA}
Centralina A	16.67^{aA}	18.21^{bA}	2.42^{dA}	3.21^{bA}	3.71^{dB}	4.63^{cA}
Inhumas Casca Roxa	13.04^{bB}	17.83^{bA}	5.36^{aA}	5.45^{aA}	6.49^{aA}	6.48^{aA}
Inhumas E	14.88^{aA}	15.79^{cA}	2.38^{dB}	3.40^{bA}	3.86^{dB}	4.55^{cA}
Jundiaí	9.96^{cA}	8.92^{eA}	1.82^{dA}	1.61^{cA}	3.39^{dA}	3.36^{eA}
Novo Cruzeiro	14.92^{aA}	14.75^{cA}	2.73^{cB}	4.39^{aA}	4.65^{cB}	5.84^{bA}
Pinheiral	13.87^{bB}	18.21^{bA}	4.47^{bA}	4.75^{aA}	5.61^{bA}	6.09^{aA}
Ugarte	15.38^{aB}	19.75^{aA}	5.68^{aA}	4.65^{aB}	6.34^{aA}	5.62^{bB}
Mean	12.83	15.92	3.42	3.78	4.60	5.12
CV, %	11.20		17.84		10.19	

The classification of bulbs according to their diameter is another essential production characteristic in garlic crops. The highest average marketable yield presented classes 5 and 6 bulbs, being 30.6% and 8.3% for 'Inhumas Casca Roxa' and 32.8% and 9.2% for 'Ugarte', in this sequence. In addition to lower marketable yield averages, 'Cateto Roxo' (43.5%) and 'Jundiaí' (50.1%) had a higher percentage of unmarketable bulbs (Figure 3).

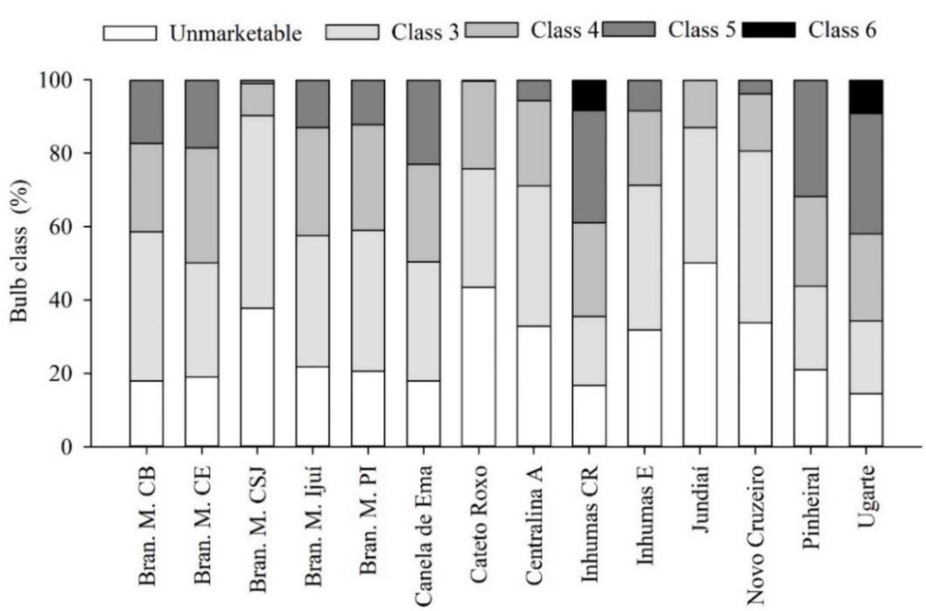

Figure 3. Percentage of garlic bulbs according to the market classification of early garlic cultivars. 2024.

Quality of early garlic cultivars

Regarding the post-harvest quality attributes of the early cultivars evaluated in low-altitude semi-arid conditions, except for pungency, a significant effect was observed for the interaction of cultivars and years of cultivation. For pungency, the cultivar and years factors had an isolated effect.

In both experiments, soluble solids of all cultivars were greater than 30%. In 2022, the highest levels of soluble solids (36.08%) were observed in 'Branco Mineiro PI' and 'Inhumas Casca Roxa', while, in 2023, 'Canela de Ema' and 'Centralina A' had the highest averages (37.00%) (Table 4).

Total solids were higher in 'Branco Mineiro PI' (45.16%) and 'Canela de Ema' (39.17%), in 2022 and 2023, respectively (Table 4). The highest industrial index in 2022 was obtained in 'Branco Mineiro PI' (36.19%), while in 2023 the highest averages occurred in 'Branco Mineiro Casca Branca', 'Branco Mineiro CE', 'Branco Mineiro CSJ', 'Branco Mineiro Ijuí', 'Canela de Ema', 'Inhumas Casca Roxa', 'Pinheiral' and 'Ugarte' (Table 4).

Table 4. Mean values of soluble solids, total solids, and industrial index of early garlic cultivars. 2024. Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other by the Scott-Knott test ($p < 0.05$) and the F test ($p < 0.05$), respectively.

Cultivars	Soluble solids		Total solids		Industrial index	
	2022	2023	2022	2023	2022	2023
	%		%			
Branco Mineiro Casca Branca	34.45^{aA}	35.04^{bA}	39.74^{cA}	37.06^{aB}	31.22^{bA}	32.40^{aA}
Branco Mineiro CE	34.18^{aA}	35.41^{bA}	41.34^{cA}	36.92^{aB}	31.47^{bA}	32.16^{aA}
Branco Mineiro CSJ	30.45^{bB}	34.83^{bA}	40.06^{cA}	37.90^{aB}	31.86^{bA}	32.55^{aA}
Branco Mineiro Ijuí	33.95^{aA}	33.90^{bA}	42.21^{bA}	37.41^{aB}	31.97^{bA}	32.70^{aA}
Branco Mineiro PI	36.00^{aA}	34.58^{bA}	45.16^{aA}	35.35^{bB}	36.19^{aA}	31.52^{aB}
Canela de Ema	33.42^{aB}	37.00^{aA}	37.59^{dA}	39.17^{aA}	26.99^{cB}	30.95^{aA}
Cateto Roxo	32.88^{bA}	34.04^{bA}	34.71^{eA}	34.00^{cA}	27.52^{cA}	27.12^{bA}
Centralina A	34.37^{aB}	36.95^{aA}	39.60^{cA}	38.15^{aA}	28.41^{cA}	28.08^{bA}
Inhumas Casca Roxa	36.08^{aA}	33.83^{bB}	39.42^{cA}	37.85^{aA}	30.64^{bA}	31.59^{aA}
Inhumas E	33.56^{aA}	35.19^{bA}	39.69^{cA}	35.97^{bB}	31.41^{bA}	32.18^{aA}
Jundiaí	31.30^{bB}	34.34^{bA}	33.36^{eA}	32.66^{cA}	24.61^{dA}	25.62^{bA}
Novo Cruzeiro	31.98^{bA}	32.94^{bA}	36.53^{dA}	35.05^{bA}	23.55^{dA}	25.52^{bA}
Pinheiral	34.45^{aA}	33.95^{bA}	39.82^{cA}	36.58^{aB}	29.58^{bA}	30.95^{aA}
Ugarte	33.94^{aA}	34.69^{bA}	37.28^{dA}	37.91^{aA}	29.42^{bB}	32.48^{aA}
Mean	33.64	34.76	39.04	36.57	29.63	30.42
CV, %	4.41		3.85		5.34	

Higher pungency was observed for the cultivars of the type Branco Mineiro (Casca Branca, CE, CSJ, Ijuí, and PI), Cateto Roxo, Inhumas Casca Roxa, Inhumas E, Pinheiral, and Ugarte with average values of 79.51 to 84.65 µmol pyruvic acid mL^{-1}. On average, the pungency among the bulbs of plants grown in 2023 was higher (83.13 µmol pyruvic acid mL^{-1}) when compared to 2022 (75.82 µmol pyruvic acid mL^{-1}) (Figure 4).

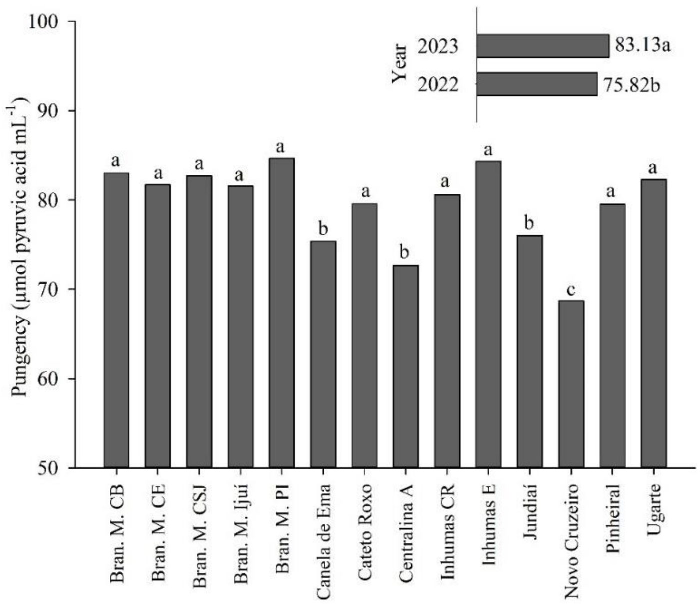

Figure 4. Pungency of early garlic cultivars. 2024. Means followed by the same letter do not differ from each other by the Scott-Knott test at ($p < 0.05$).

DISCUSSION

Due to the intrinsic characteristics of each cultivar, differences between the materials in the growth, yield, and postharvest evaluations were expected. However, the findings obtained in this research revealed that the climatic variations existing in the two experiments also influenced some cultivars in each cycle, corroborating the statement that garlic is a crop sensitive to climatic factors (Atif et al., 2021).

Among the materials evaluated, the cultivars from the group Branco Mineiro, Casca Branca and CE, Centralina A, Inhumas Casca Roxa, Pinheiral, and Ugarte decreased in height in 2023. These cultivars may have greater sensitivity to higher temperatures and, or, lower rainfall and relative air humidity, which were characteristics observed that year since the garlic plants' height is the result of the interaction of environmental and genetic factors (Honorato et al., 2013).

In our research, we also observed variations between cultivars regarding plant sprouting. Only 'Cateto Roxo' and 'Jundiaí' did not show sprouting in the two cycles, which may indicate that these materials are not susceptible, under the conditions studied, to this anomaly, which is characterized by the axillary bud outgrowth or between the leaves of the pseudostem, which can lead to the opening and exposure of the cloves. The occurrence of this physiological disorder is not desirable as it reduces garlic yield and, consequently, its marketable value (Morais et al., 2023) and can be caused by temperature, photoperiod, and excess water and N (Michael et al., 2018).

Considering the difference in the sprouting of 'Novo Cruzeiro' between the experiments and analyzing the climatic data over the years, it is possible to assume that this material is more sensitive to environmental conditions. In 2022 (average of 27.3 °C and 336.6 mm) milder temperatures and higher rainfall were recorded compared to 2023 (average of 25.9 °C and 85.6 mm), which are some factors that influence sprouting.

The number of cloves per bulb varies according to the characteristics of each cultivar and may be influenced by environmental factors (Lucena et al., 2016; Morais et al., 2023). This research findings corroborate the statements of the aforementioned authors, considering the increase in the number of cloves per plant in 'Branco Mineiro Ijuí', 'Canela de Ema', 'Inhumas Casca Roxa', 'Pinheiral', and 'Ugarte', in 2023, a year with a higher temperature compared to 2022. However, more cloves per plant does not necessarily mean higher marketable value and market acceptance, since consumers prefer larger bulbs with fewer cloves (Lopes et al., 2016).

Another factor that may justify the increase in the number of cloves in 2023 is the production site of garlic seed cloves. The first experiment (2022) used garlic seed clove produced in a region of milder temperature, which may imply lower bulbification in common garlic cultivars in the first crop in a region of higher temperature (Luís et al., 2020), as occurred in the present research. Therefore, the results suggest that, depending on the cultivar, when using garlic seed cloves of early cultivars from another region, fewer cloves should be considered in the first year of production.

The difference in the number of cloves per bulb between the experiments did not mean a difference in the average mass of bulbs in the plants between the cycles, with an isolated effect of the cultivar factor and the years. 'Inhumas Casca Roxa' and 'Ugarte' had the highest average bulb mass and also, greater height and number of leaves. We found that plant height affects the average mass of the bulbs through a moderate correlation between the variables (Figure 5). Thus, possibly there was higher photosynthetic activity and production of photoassimilates translocated to the bulbs (Desta et al., 2021), resulting in higher weight.

The marketable and total yield of garlic bulbs varied according to the cultivars and, in some cases, the materials also showed different yields according to the years. The higher yield averages observed in 'Inhumas Casca Roxa' and 'Ugarte' can be explained by their adaptability to environmental conditions, which resulted in plants with greater height, allowing higher production of photoassimilates translocated to the bulb, to increase its average mass and, consequently, yield.

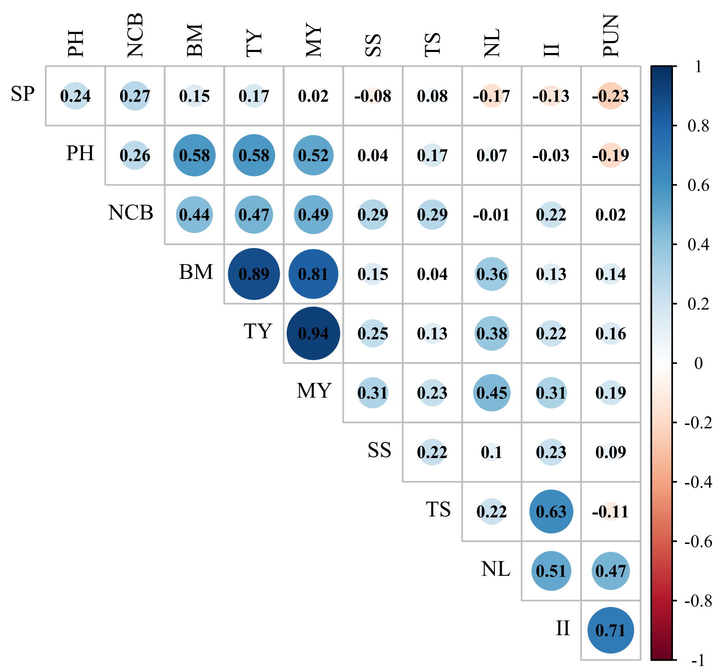

Figure 5. Pearson's correlation of biometric, yield, and quality characteristics of early garlic cultivars. SP: Sprouted plants; PH: plant height; NCB: number of cloves per bulb; BM: bulb mass; TY: total Yield; MY: marketable yield; SS: soluble solids; TS: total solids; NL: number of leaves; II: industrial index; PUNG: pungency. 2024.

In some cultivars, experimental conditions affected soluble solids (SS) and total solids (TS). The SS of some cultivars may vary depending on the interaction of the material's genetics with the environment (Akan, 2019). In 'Branco Mineiro CSJ', 'Canela de Ema', 'Centralina A', and 'Jundiaí', SS increased in 2023, a year with higher temperatures and lower rainfall, which may have caused greater transpiration and concentration of soluble compounds in the bulbs. However, the opposite occurred for 'Inhumas Casca Roxa', suggesting the effect of other factors on the SS content of this cultivar.

Bulbs with high levels of TS are desirable as they allow for longer storage time and post-harvest quality, essential for fresh consumption, and industrial dehydration, important for the processed food market (Barboza et al., 2020). Despite all values higher than 30%, we found that for all cultivars from the Branco Mineiro group, 'Inhumas E', and 'Novo Cruzeiro', TS decreased in 2023. These findings may mean that the cultivation of these materials in higher temperatures and less rainfall decreases the TS and, consequently, the quality of the bulbs.

One of the most essential post-harvest quality attributes of garlic is pungency, which is related to the flavor and aroma of the bulb. The pyruvic acid content determines this characteristic, and cultivars with high concentrations are desirable, either for fresh consumption and/or for industrialization due to loss during processing (Lopes et al., 2016; Lucena et al., 2016; Bessa et al., 2020).

The main factor influencing the pungency of garlic bulbs is the genetic characteristics of the cultivars (Ammarellou et al., 2022; Li et al., 2022), with a positive correlation between the number of leaves and pungency (Figure 5). We also found that the average pungency between the experiments differed, with a higher average in 2023, which may have occurred due to the higher temperature, providing the accumulation of pyruvic acid in the bulbs (Abedi et al., 2013).

The pungency and concentration of TS directly impact the industrial index (Figure 5). Therefore, bulbs with a high industrial index mean desirable aroma and yield for processing (Lopes et al., 2016). From this, the cultivars from the Branco Mineiro group (Casca Branca, CE, CSJ, Ijuí, and PI), Inhumas Casca Roxa, Inhumas E, Pinheiral, and Ugarte have desirable aroma and use for industrialization.

Evaluating early garlic cultivars grown in low-altitude semi-arid regions is essential for identifying potential materials for production under these conditions. From the results obtained in this research, we highlight 'Inhumas Casca Roxa' and 'Ugarte' (Figure 6) due to their biometric performance, utilization, and post-harvest quality attributes. However, based on the findings presented here, we emphasize the need to advance in research dedicated to crop management to achieve the maximum agronomic performance of the highlighted materials.

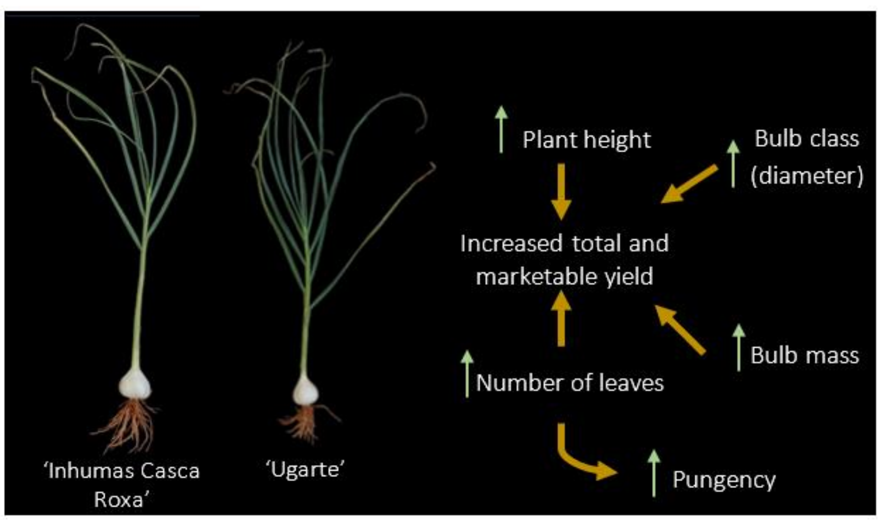

Figure 6. Determinant characteristics in early garlic cultivars yield in semiarid conditions at low-altitude. 2024.

CONCLUSIONS

The agronomic performance of early garlic cultivars in low-altitude semi-arid regions may vary depending on the environmental conditions of the growing season.

The use of 'Inhumas Casca Roxa' and 'Ugarte' is recommended due to the yield and production of bulbs with post-harvest characteristics and desirable classification by the fresh and industrial consumption market.

Author contribution

Conceptualization: F.P-D., R.T.O-R., C.M.Q-G., S.F-E., H.A.C-L. Methodology: F.P-D., R.T.O-R., G.M-E., C.M.Q-G., S.F-E. Validation: F.P-D., R.T.O-R., C.M.Q-G., M.S.S-L., H.A.C-L., B.F.M-G., C.G-F. Formal analysis: F.P-D., C.G-L., R.T.O-R., M.S.S-L., B.F.M-G., C.G-F. Investigation: F.P-D., R.T.O-R., G.M-E., N.S-E., C.M.Q-G., B.M.S-L., M.S.S-L., S.F-E., H.A.C-L., B.F.M-G., C.G-F,. M.C.C-R. Resources: C.G-L., V.R-F. Data curation: F.P-D., C.M.Q-G., B.M.S-L. Writing-original draft: F.P-D., C.G-L., M.C.C-R. Writing-review & editing: F.P-D., C.G-L., M.C.C-R. Supervision: C.G-L., V.R-F., M.C.C-R., F.P-D. Project administration: C.G-L., V.R-F., M.C.C-R., F.P-D. Funding acquisition: B.L. All co-authors reviewed the final version and approved the manuscript before submission.

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