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# Performance of agro-ecological based carrot cultivars affected by plant arrangement

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**ABSTRACT.** Carrot is a vegetable of worldwide importance due to its high nutritional quality and wide application in food. The adjustment of plant arrangement in carrot cultivars is decisive for the productivity and quality of roots; in a conventional system, a spacing between rows of 20 cm is indicated. However, few studies address the interaction cultivar versus row spacing in an agro-ecological cropping system, suitable for production without pesticides and fertilizers. We examined the performance of carrot cultivars at different spacing between rows on the yield and quality of roots in an agro-ecological system, with the objective of greater sustainability of food security cultivation. This experiment was carried out in Augusto Pestana, RS, Brazil, from February to June, in 2019 and 2020. The design was a randomized block with three replications in a 5x3 factorial scheme, for five carrot cultivars (Danvers, Brasília Calibrada Media, Nantes, Esplanada and Brasília Nina) and three spacings between lines (10, 15 and 20 cm), respectively. The cultivars used are the most used accepted genotypes for cultivation in Brazil. In the study, the indicators of productivity and quality of roots were evaluated. The Brasília Nina carrot cultivar showed high performance in root yield and quality, mainly in the 15 cm spacing between rows in an agro-ecological system. The production of carrot roots with quality and free from toxic contaminants, contributes to the valorization of the product for commercialization and the production of food with greater sustainability and food safety.

**Key words:** *Daucus carota*; Healthy food; Organic crop; Food safety

## INTRODUCTION

Carrots (*Daucus carota*) are one of the most important vegetables in Brazil and in the world; it is the root vegetable with the highest economic value (Carvalho et al., 2018; Patkowska et al., 2020). Carrots are interesting for the human consumption due to their soft texture and pleasant taste, and an excellent source of vitamin A, fiber and bioactive compounds such as β-carotene, which provides several health benefits (Resende et al., 2016; Gomes et al., 2019). Due to a greater concern with health and consumption of healthier foods, there is a need to develop more sustainable crop systems that guarantee food safety. (Toni et al., 2020). Food and nutrition safety consists of realizing the right for accessing quality food, in a sufficient quantity, without compromising other essential needs (Trivellato et al., 2019). However, due to the current form of production, based on the application of pesticides, a high rate of toxic contaminants is found in food. (Gomes et al., 2020). Besides, the constant use of pesticides has caused numerous environmental problems related to water, air and soil contamination, loss of biodiversity and other damage to agroecosystems (Nogueira et al., 2020). Almost all vegetables produced and consumed in Brazil and in the world come from systems that use large amounts of pesticides and fertilizers. Although they show results obtained from increased productivity, they bring serious damage to health and the environment. A condition that highlights the need to develop more sustainable crops, without the use of agrochemicals with a guarantee of satisfactory productivity (Patkowska et al., 2020).

Agro-ecological-based production emerges as a promising alternative to conventional practices, with managements that are characterized by the minimal use of external inputs and a limited amount of mineral fertilizers, ensuring productivity with economic return (Carvalho et al., 2018; Bender et al., 2020). In this context, the technical criteria that interfere in the agronomic performance of carrots in an agro-ecological based system must be observed mainly due to the characteristics of cultivars and the management in arrangement of plants on productivity and root quality (Lopes et al., 2008; Resende et al., 2016; Silva et al., 2017).

Analysis of carrot cultivars under different row spacing conditions can guarantee the development of roots with satisfactory quality and productivity in agro-ecological based management, providing the consumer with a healthier and more sustainable product. Therefore, the goal of this study is the performance of carrot cultivars at different spacing between rows on the yield and quality of roots in an agro-ecological system, in the proposal of greater sustainability of food security cultivation.

## MATERIAL AND METHODS

This work was developed at the Regional Institute of Rural Development, which belongs to the Regional University of Northwestern, Rio Grande do Sul, in the city of Augusto Pestana, RS, Brazil (28°26'25" S latitude and 54°00'07" W of longitude). The soil of the experimental unit is classified as a typical dystroferric Red Latosol, and according to the Köeppen climate classification, the region's climate fits the description of Cfa (humid subtropical). The study was carried out between February and June, 2019 and 2020, following an experimental design of randomized blocks with three replications in a 5 x 3 factorial scheme, with five carrot cultivars (Danvers, Brasília Calibrada Média, Nantes, Esplanada and Brasília Nina), and with three different spacings between lines (10, 15 and 20 cm). Each experimental unit consisted of a plot of five lines with a length of 1.35 m, and with a variation of area in the spacing between lines of 10, 15 and 20 cm, ranging from 0.68, 1.01 and 1.35 $m^2$, respectively.

Approximately three weeks before the implementation of the experiment, 14 liters $m^{-2}$ of tanned bovine manure without the presence of straw were applied. A few days before sowing, the soil analysis of the experimental area was carried out, presenting the following characteristics: Clay = 60%; pH=5.8; SMP Index=6.2; P=20.4 mg $dm^{-3}$; K=216 mg $dm^{-3}$; MO=2.6%; Al=0.0 cmolc $dm^{-3}$; Ca=6.7 cmolc $dm^{-3}$; Mg= 3.3 cmolc $dm^{-3}$; Cu= 13.6 mg $dm^{-3}$; Zn=9.4 mg $dm^{-3}$; Mn=64.1 mg $dm^{-3}$; S=3.0 mg $dm^{-3}$. The tillage for the construction of the beds was carried out by plowing and harrowing with the use of a bedformer. Sowing was carried out on February 14$^{th}$, 2019, and on March 16$^{th}$, 2020.

Sowing was carried out manually in both years of crop, incorporating the fertilization in the soil for the culture according to the Soil Chemistry and Fertility Commission - RS/SC (2016), and considering the values obtained in the soil analysis. In this way, it was applied approximately 337 g $m^{-2}$ of laying bed. Approximately 30 days after sowing, the thinning management was carried out in order to reach a minimum distance of 10 centimeters between plants in the row. To ensure a good development of the plants, approximately 40 days after emergence, foliar fertilization of a biofertilizer obtained through the fermentation of chicken litter, also called "Franfresco" was carried out for the supply of nitrogen (Claro, 2001).

In 2019, the control of pest insects (*Agrotis ipsilon*, *Spodoptera frugiperda*, *Diabrotica speciosa*, *Epicauta atomaria*, *Aphis gossypii*, *Cavariella aegopodii* and *Myzus persicae*) was by applying a solution of tobacco water, at concentrations of 3, 5 and 9%, two applications of Neem oil, with 25 ml for every ten liters of water, one application of *Beauveria bassiana* (BeauveControl®), with 30 grams to ten liters of water. An application of water with “soap” (a solid compound produced from glycerin, alcohol, soda and fat) was also carried out, with 50g of soap for 5 liters of water. All these control methods are validated for agro-ecological crops, according to Claro (2001). Applications in pest control were carried out according to the appearance of insects. In 2020, there was no need to control insect pests, just a monitoring throughout the crop cycle. To control invasive plants, the manual removal was carried.

The irrigation of beds was performed by sprinkler, with a flow rate of 0.158 mm $min^{-1}$ for each sprinkler. To estimate the gross lamina (GL) of water required by the crop per day, it was used the formula $GL = (Kc.Eda)/Ae$ (Andriolo, 2013), where the Kc of the crop was found in published data (Marouelli et al., 1996). The evapotranspiration data (Eda) were obtained from the Regional Institute of Rural Development meteorological station located approximately 500 meters from the experiment and the application efficiency (Ae) was 0.80 for the used system. Thus, considering the applied depth (mm $min^{-1}$) by each sprinkler, it was estimated the necessary irrigation time to reach the required gross depth per day.

The harvest was carried out according to the recommendation for each cultivar. The cultivar Brasília Calibrada Media was harvested approximately 75 days after emergence; the cultivars Brasília Nina and Esplanada at 80 days after emergence; and the cultivars Danvers and Nantes at 100 days after the emergency. Before removing plants from the soil, it was counted the number of plants (NP, nº) present in each of the three central lines of each plot.

The productivity indicators evaluated were the Biological Productivity (BP, kg $m^{-2}$), obtained by weighing the entire plant of all plants harvested in the three central lines of each plot. Afterwards, it was carried out the separation of leaves and roots and the Leaf Productivity (LP, kg $m^{-2}$) taken by weighing the leaves of all plants and the Root Productivity (RP, kg $m^{-2}$), taken by weighing the roots. The Crop Index (CI, kg $kg^{-1}$) was obtained by dividing Root Productivity by Biological Productivity. To obtain the Length (CR, cm) and Root Diameter (DR, mm), all roots were individually measured with the aid of a ruler and a caliper, respectively. The diameter was measured in the central part. The productivity data obtained in this study are presented in kg $m^{-2}$. Comparing the results in relation to productivities obtained in other studies, productivity data were transformed into tons per hectare (t $ha^{-1}$). The quality indicators of roots were also evaluated, and visually classified according to their characteristics in forked, crooked, woody, small, commercial, broken and cracked.

The data obtained were subjected to analysis of variance to detect the main and interaction effects on carrot productivity indicators. Afterwards, a comparison test of means by Scott and Knott and a linear regression test with significance analysis of the angular coefficient by t test was performed. All analyzes considered were tested at a 5% probability of error level. For the carrot quality indicators, descriptive statistics and classification in upper (U) and lower (L) were used by the mean plus and minus the standard deviation considered. For the variables forked, crooked, woody, small, broken and cracked, the superior cultivars were those that presented values equal to or less than the mean minus one standard deviation. For the variable of commercial interest, cultivars were classified as superior when the values obtained were equal to or greater than the average plus one standard deviation. All analyses used the GENES Software (Cruz, 2006).

## RESULTS AND DISCUSSION

In the year 2019 (Figure 1) the total volume of precipitation was 584 mm, well distributed during the carrot growing cycle. The air temperature was high, with an average of 20°C, due to sowing carried out in February. In that same year, the temperature for most of the cycle was higher than the limit considered adequate for the development of carrot shoots and roots. In 2020 (Figure 1), sowing in March contributed to milder temperatures, finding much of the cycle within the limit considered ideal. The precipitation with a volume of 332 mm, although less than 2019, was also well distributed throughout the cycle. However, to ensure adequate soil moisture conditions, the irrigation system was activated. The conditions presented mainly by the air temperature during the cycle explain the lower biological and root productivity in 2019. These results are similar to those observed by Ferracin et al. (2020), in which they comment that higher temperatures during the cultivation cycle cause lower productivity. It is noteworthy that the carrot is a species adjusted to milder temperatures and most varieties grown in Brazil require temperatures between 15ºC and 20ºC for the proper development of the shoot and root. Colombari et al. (2018) report in their studies the high productivities obtained with carrots under development conditions with an average temperature of 18ºC. Saha et al. (2016) observed that temperatures above 25°C result in lower productivity and formation of non-marketable roots.

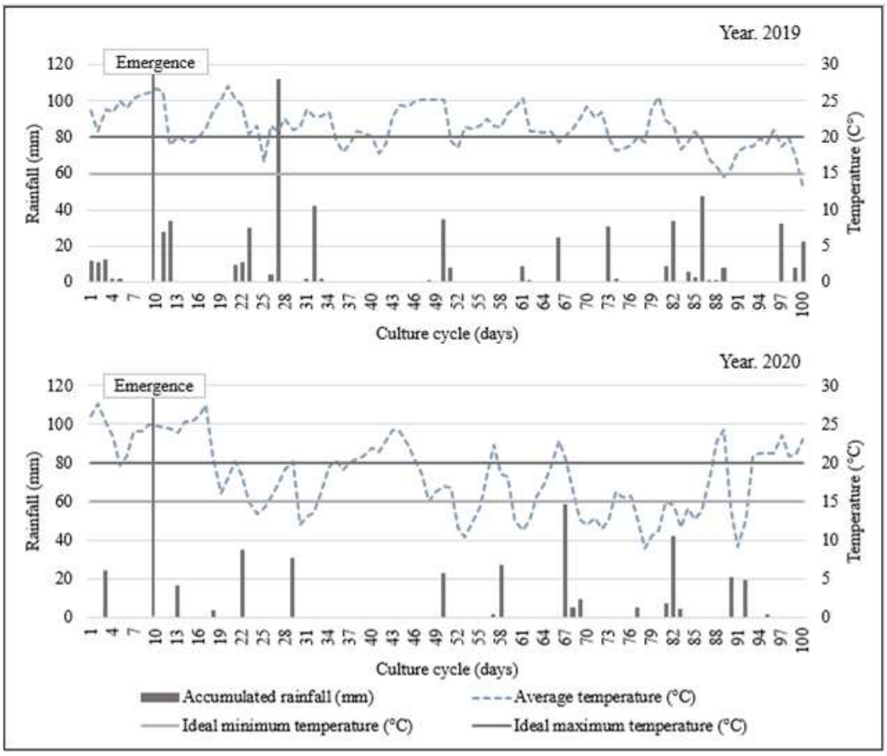


**Figure 1**. Rainfall and average temperature during the carrot growing cycle in 2019 and 2020. Source: Regional Institute of Rural Development/UNIJUÍ Meteorological Station, Augusto Pestana, RS, Brazil, 2019 and 2020. * Ideal minimum and maximum temperatures for carrot cultivation according to published data.

As previously reported, although the distribution of rainfall throughout the cycle in different years was verified, sprinkler irrigation was necessary, especially at the beginning of carrot development by placing a "low tunnel" (small plastic greenhouse over the beds) over the beds (Figure 2). The "low tunnel" application was essential in the first 30 days after sowing, considering that the species is sensitive to high rainfall. In the years 2019 and 2020, the applied water depth was 294 and 339 mm, respectively, close to the values required by the species, which, according to Marouelli et al. (2007), range from 350 to 550 mm. These authors comment that demand for irrigation water depends on meteorological conditions, cycle duration, the cultivar, the irrigation system and the daily demand, which increases slightly with the advance of plant development.

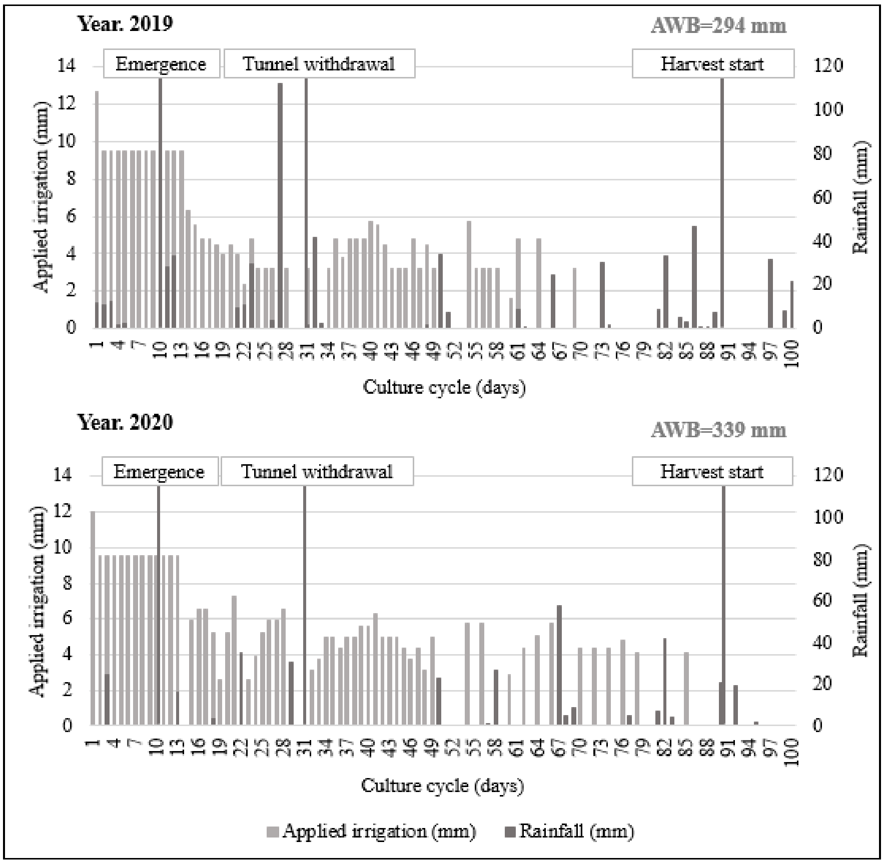


**Figure 2.** Precipitation and irrigation applied during the carrot growing cycle in 2019 and 2020. AWB= applied water blade (mm).

Table 1 analyzes the quality of roots in 2019 with the spacing between rows of 10 cm, and it indicates a superiority of the Brasília Calibrada Media cultivar in not expressing bifurcated roots, however, it is within the average in the expression of the other variables compared to the other cultivars. In this condition, the Brasília Nina cultivar showed superiority in the lowest expression of small roots and the highest percentage of roots with the adequate commercialization pattern. With the 15 cm spacing between lines, the cultivar Esplanada shows inferiority in relation to the others due to the high expression of bifurcated roots. In this spacing, the cultivar Brasília Nina also expressed the lowest percentage of small roots and with superiority in the pattern of commercial roots. The other cultivars in this condition expressed similarity, except for the cultivar Danvers, which was inferior to the others due to the higher percentage of small roots. With the 20 cm spacing between lines, Danvers stood out for the absence of forked roots, however, with a high percentage of small and commercial standard roots. Cultivar Esplanada showed a more expressive value of crooked roots, classified as inferior in relation to the others. In this condition, the cultivar Brasília Nina also stands out with even more expressive results of roots in the commercial pattern. In a general analysis, analyzing mainly the number of small roots and the adequate commercialization pattern, the 15 and 20 cm spacings were more effective in improving the expression of these qualitative characteristics in relation to the 10 cm spacing. On the other hand, in these variables, the variation between the points of 15 and 20 cm of spacing between lines showed no change, indicating that the spacing between lines of 15 cm is more suitable for better results in quality standard and greater ease of coverage of soil through the canopy.

**Table 1.** Classification of carrot roots by quality indicators in 2019.

| Cultivars | S | FO | | CR | | WO | | SM | | CO | | BR | | CA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | % | S | % | S | % | S | % | S | % | S | % | S | % |
| | | Line spacing 10 cm | | | | | | | | | | | | | |
| B. C. Média | 46 | 0 | $^{U}$0 | 2 | 4 | 0 | 0 | 37 | 80 | 6 | 13 | 0 | 0 | 0 | 0 |
| B. Nina | 68 | 2 | 3 | 5 | 7 | 0 | 0 | 39 | $^{U}$57 | 21 | $^{U}$31 | 0 | 0 | 1 | 1 |
| Danvers | 63 | 3 | 5 | 2 | 3 | 0 | 0 | 56 | $^{L}$89 | 2 | 3 | 0 | 0 | 0 | 0 |
| Esplanada | 65 | 7 | $^{L}$11 | 2 | 3 | 0 | 0 | 49 | 75 | 6 | 9 | 0 | 0 | 0 | 0 |
| Nantes | 69 | 8 | $^{L}$12 | 7 | 10 | 0 | 0 | 48 | 69 | 6 | 9 | 0 | 0 | 0 | 0 |
| Average | - | 4 | 6A | 4 | 6A | 0 | 0A | 46 | 75A | 8 | 13B | 0 | 0A | 0 | 0A |
| SD | - | 3 | 5 | 3 | 5 | 0 | 0 | 8 | 13 | 8 | 11 | 0 | 0 | 1 | 1 |
| Upper ( $^{U}$ ) | - | 1 | 1 | 1 | 1 | 0 | 0 | 38 | 62 | 16 | 24 | 0 | 0 | 0 | 0 |
| Lower ( $^{L}$ ) | - | 7 | 11 | 7 | 11 | 0 | 0 | 54 | 88 | 1 | 2 | 0 | 0 | 1 | 1 |
| | | Line spacing 15 cm | | | | | | | | | | | | | |
| B. C. Média | 36 | 2 | 5 | 1 | 3 | 0 | 0 | 21 | 58 | 10 | 28 | 1 | 3 | 1 | 3 |
| B. Nina | 42 | 2 | 5 | 4 | 9 | 1 | 2 | 20 | $^{U}$48 | 15 | $^{U}$36 | 0 | 0 | 0 | 0 |
| Danvers | 32 | 1 | 3 | 1 | 3 | 0 | 0 | 25 | $^{L}$78 | 6 | 19 | 0 | 0 | 0 | 0 |
| Esplanada | 32 | 5 | $^{L}$16 | 3 | 9 | 0 | 0 | 20 | 62 | 5 | 16 | 0 | 0 | 0 | 0 |
| Nantes | 44 | 4 | 9 | 5 | 11 | 0 | 0 | 28 | 64 | 7 | 16 | 0 | 0 | 0 | 0 |
| Average | - | 3 | 7A | 3 | 7A | 0 | 0A | 23 | 61B | 9 | 23A | 0 | 0A | 0 | 0A |
| SD | - | 2 | 6 | 2 | 6 | 1 | 1 | 7 | 13 | 4 | 12 | 1 | 2 | 1 | 1 |
| Upper ( $^{U}$ ) | - | 1 | 1 | 1 | 1 | 0 | 0 | 16 | 48 | 13 | 35 | 0 | 0 | 0 | 0 |
| Lower ( $^{L}$ ) | - | 5 | 13 | 5 | 13 | 1 | 1 | 29 | 74 | 4 | 11 | 1 | 2 | 1 | 1 |
| | | Line spacing 20 cm | | | | | | | | | | | | | |
| B. C. Média | 30 | 2 | 7 | 3 | 10 | 0 | 0 | 15 | 50 | 9 | 30 | 1 | 3 | 0 | 0 |
| B. Nina | 33 | 2 | 6 | 1 | 3 | 0 | 0 | 17 | 51 | 13 | $^{U}$40 | 0 | 0 | 0 | 0 |
| Danvers | 31 | 0 | $^{U}$0 | 1 | 3 | 0 | 0 | 26 | $^{L}$84 | 3 | $^{L}$10 | 1 | 3 | 0 | 0 |
| Esplanada | 33 | 3 | 9 | 5 | $^{L}$15 | 0 | 0 | 17 | 51 | 9 | 27 | 0 | 0 | 0 | 0 |
| Nantes | 34 | 4 | $^{L}$12 | 3 | 9 | 0 | 0 | 22 | 65 | 5 | 15 | 0 | 0 | 0 | 0 |
| Average | - | 2 | 6A | 2 | 8A | 0 | 0A | 20 | 60B | 8 | 24A | 0 | 1A | 0 | 1A |
| SD | - | 2 | 5 | 2 | 7 | 0 | 0 | 6 | 16 | 5 | 13 | 1 | 3 | 0 | 2 |
| Upper ( $^{U}$ ) | - | 0 | 1 | 0 | 1 | 0 | 0 | 14 | 44 | 13 | 37 | 0 | 0 | 0 | 0 |
| Lower ( $^{L}$ ) | - | 4 | 11 | 5 | 15 | 0 | 0 | 26 | 76 | 3 | 11 | 1 | 4 | 1 | 3 |

FO=forked; CR=crooked; WO=woody; SM=small; CO=commercial; BR=broken; CA=cracked; B. C. Média= Brasília Calibrada Média; B. Nina=Brasilia Nina; S=sample of the number of roots collected in 1 m² (Observed value); U=greater than the mean minus one standard deviation for the variables forked root, crooked, woody, small, broken and cracked, greater than the mean plus one standard deviation for the variable of commercial interest; I=lower mean minus one standard deviation for the forked root, crooked, woody, small, broken and cracked variables, lower mean minus one standard deviation for the variable of commercial interest. SD= standard deviation. Note: Total number of carrots that should be in each m² of spacing used: 10 cm (74 plants), 15 cm (49 plants) and 20 cm (37 plants). Averages followed by the same letter in the column constitute a statistically homogeneous group by the Scott and Knott test at 5% probability of error.

In Table 2, in the year 2020 for the spacing between rows of 10 cm, the cultivar Brasília Nina expressed superiority in the smaller number of forked and crooked roots. The inferior performance at Danvers was verified in the expression of forked roots and commercial pattern and, at Nantes, in relation to the bifurcation of roots. In this year of cultivation, the superiority of roots with commercial pattern was obtained by the cultivar Brasília Calibrada Media. With the 15 cm spacing between lines, almost all of the analyzed cultivars were within the average pattern, with the exception of Nantes due to the inferiority in the expression of crooked roots. With the 20 cm row spacing, although Brasília Nina expressed inferiority in the percentage of bifurcated roots, it was the only cultivar with superiority in the absence of crooked roots. All cultivars expressed similarity within the average range in the expression of small roots and commercial pattern, except for the cultivar Nantes, which was inferior. Due to better expression of quality and arrangement of plants in the canopy for closing between rows, it can be seen that the spacing of 15 cm is technically the best fit under the conditions studied.

**Table 2.** Classification of carrot roots by quality indicators in 2020.

| Cultivars | S | FO | | CR | | WO | | SM | | CO | | BR | | CA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | % | S | % | S | % | S | % | S | % | S | % | S | % |
| | | Line spacing 10 cm | | | | | | | | | | | | | |
| B. C. Média | 74 | 2 | 3 | 4 | 5 | 0 | 0 | 44 | 59 | 24 | $^{U}$32 | 1 | 1 | 0 | 0 |
| B. Nina | 67 | 1 | $^{U}$1 | 1 | $^{U}$1 | 0 | 0 | 52 | 78 | 13 | 19 | 0 | 0 | 0 | 0 |
| Danvers | 70 | 6 | $^{L}$9 | 3 | 4 | 1 | 1 | 55 | 79 | 4 | $^{L}$6 | 0 | 0 | 0 | 0 |
| Esplanada | 68 | 3 | 4 | 6 | $^{L}$9 | 0 | 0 | 37 | $^{U}$54 | 18 | 26 | 2 | 3 | 1 | 1 |
| Nantes | 74 | 7 | $^{L}$9 | 3 | 4 | 0 | 0 | 50 | 68 | 13 | 18 | 0 | 0 | 0 | 0 |
| Average | - | 4 | 5A | 3 | 5A | 0 | 0A | 48 | 68A | 15 | 21A | 1 | 1A | 0 | 0A |
| SD | - | 3 | 4 | 2 | 3 | 1 | 1 | 9 | 12 | 8 | 11 | 1 | 1 | 1 | 1 |
| Upper ($^{U}$) | - | 1 | 1 | 1 | 2 | 0 | 0 | 39 | 56 | 23 | 32 | 0 | 0 | 0 | 0 |
| Lower ($^{L}$) | - | 7 | 9 | 6 | 8 | 1 | 1 | 57 | 80 | 7 | 10 | 1 | 2 | 1 | 1 |
| | | Line spacing 15 cm | | | | | | | | | | | | | |
| B. C. Média | 49 | 3 | 6 | 2 | 4 | 0 | 0 | 22 | 45 | 21 | 43 | 1 | 2 | 1 | 2 |
| B. Nina | 29 | 2 | 7 | 2 | 7 | 0 | 0 | 14 | 48 | 9 | 31 | 0 | 0 | 2 | 7 |
| Danvers | 49 | 5 | 10 | 2 | 4 | 1 | 2 | 27 | 55 | 14 | 29 | 0 | 0 | 0 | 0 |
| Esplanada | 49 | 4 | 8 | 2 | 4 | 0 | 0 | 22 | 45 | 19 | 39 | 2 | 4 | 0 | 0 |
| Nantes | 49 | 6 | 12 | 7 | $^{L}$14 | 1 | 2 | 23 | 47 | 13 | 26 | 0 | 0 | 0 | 0 |
| Average | - | 4 | 8A | 3 | 6A | 0 | 0A | 22 | 49B | 12 | 34A | 1 | 1A | 1 | 2A |
| SD | - | 2 | 5 | 3 | 6 | 1 | 1 | 6 | 11 | 6 | 10 | 1 | 1 | 1 | 3 |
| Upper ($^{U}$) | - | 2 | 3 | 0 | 0 | 0 | 0 | 16 | 38 | 18 | 44 | 0 | 0 | 1 | 0 |
| Lower ($^{L}$) | - | 6 | 13 | 6 | 12 | 1 | 1 | 27 | 60 | 6 | 24 | 1 | 2 | 2 | 5 |
| | | Line spacing 20 cm | | | | | | | | | | | | | |
| B. C. Média | 36 | 4 | 11 | 3 | 8 | 0 | 0 | 15 | 42 | 15 | 42 | 0 | 0 | 0 | 0 |
| B. Nina | 29 | 4 | $^{L}$14 | 0 | $^{U}$0 | 0 | 0 | 11 | 38 | 14 | 48 | 0 | 0 | 0 | 0 |
| Danvers | 36 | 3 | 8 | 2 | 5 | 1 | 3 | 19 | 53 | 11 | 30 | 0 | 0 | 0 | 0 |
| Esplanada | 37 | 3 | 8 | 2 | 5 | 0 | 0 | 16 | 43 | 16 | 43 | 0 | 0 | 0 | 0 |
| Nantes | 37 | 4 | 11 | 2 | 5 | 0 | 0 | 22 | $^{L}$59 | 9 | $^{L}$24 | 0 | 0 | 0 | 0 |
| Average | - | 3 | 10A | 2 | 5A | 0 | 0A | 16 | 45B | 13 | 39A | 0 | 0A | 0 | 1A |
| SD | - | 1 | 3 | 1 | 4 | 0 | 1 | 5 | 10 | 4 | 12 | 0 | 0 | 0 | 1 |
| Upper ($^{U}$) | - | 2 | 7 | 0 | 1 | 0 | 0 | 12 | 35 | 17 | 51 | 0 | 0 | 0 | 0 |
| Lower ($^{L}$) | - | 5 | 13 | 3 | 9 | 1 | 1 | 21 | 55 | 9 | 27 | 0 | 0 | 0 | 2 |

FO=forked; CR=crooked; WO=woody; SM=small; CO=commercial; BR=broken; CA=cracked; B. C. Média= Brasília Calibrada Média; B. Nina=Brasilia Nina; S=sample of the number of roots collected in 1 m² (Observed value); U=greater than the mean minus one standard deviation for the variables forked root, crooked, woody, small, broken and cracked, greater than the mean plus one standard deviation for the variable of commercial interest; I=lower mean minus one standard deviation for the forked root, crooked, woody, small, broken and cracked variables, lower mean minus one standard deviation for the variable of commercial interest. SD= standard diviation. Note: Total number of carrots that should be in each m² of spacing used: 10 cm (74 plants), 15 cm (49 plants) and 20 cm (37 plants). Averages followed by the same letter in the column constitute a statistically homogeneous group by the Scott and Knott test at 5% probability of error.

In Table 3 of quantitative variables, the analysis of variance of the effects of cultivars and row spacing indicates change in carrot productivity indicators, with no differences in spacing on harvest index and root diameter in 2019. In 2020, only the leaf productivity and harvest index variables showed differences between cultivars, with the biological, leaf and root productivity altered only by the spacing between rows. The interaction effects were not significant, allowing for a management of plant arrangement regardless of the genetic profile of each cultivar.

**Table 3.** Analysis of variance of carrot productivity indicators by different cultivars and row spacing.

| Source of variation | DF | Medium square | | | | | |
|---|---|---|---|---|---|---|---|
| | | BP (kg m$^{-2}$) | LP (kg m$^{-2}$) | RP (kg m$^{-2}$) | CI (kg kg$^{-1}$) | LR (cm) | RD (cm) |
| | | 2019 | | | | | |
| Block | 2 | 0.5343 | 0.1378 | 0.1454 | 0.0009 | 0.4667 | 0.0753 |
| Cultivars (C) | 4 | 6.4066* | 0.9382* | 2.5939* | 0.0101* | 13.7444* | 0.4021* |
| Spacing (S) | 2 | 12.9033* | 2.8739* | 3.5968* | 0.0008$^{ns}$ | 5.6000$^{ns}$ | 0.2692$^{ns}$ |
| C x S | 8 | 0.8760$^{ns}$ | 0.1524$^{ns}$ | 0.3731$^{ns}$ | 0.0007$^{ns}$ | 0.5444$^{ns}$ | 0.0220$^{ns}$ |
| Residue | 28 | 0.6983 | 0.1536 | 0.2258 | 0.0006 | 1.4905 | 0.0343 |
| Total | 44 | | | | | | |
| Overall average | | 3.77 | 1.71 | 2.08 | 0.55 | 13.20 | 2.60 |
| CV (%) | | 22.17 | 22.97 | 22.82 | 4.49 | 9.25 | 7.12 |
| | | 2020 | | | | | |
| Block | 2 | 0.4120 | 0.0301 | 0.5093 | 0.0043 | 1.6222 | 0.0285 |
| Cultivars (C) | 4 | 2.8398$^{ns}$ | 0.4806* | 1.5340$^{ns}$ | 0.0132* | 8.7444$^{ns}$ | 0.0726$^{ns}$ |
| Spacing (S) | 2 | 16.2762* | 1.7823* | 7.3353* | 0.0012$^{ns}$ | 1.1556$^{ns}$ | 0.0059$^{ns}$ |
| C x S | 8 | 1.1166$^{ns}$ | 0.1409$^{ns}$ | 0.5422$^{ns}$ | 0.0012$^{ns}$ | 1.2111$^{ns}$ | 0.0368$^{ns}$ |
| Residue | 28 | 0.5865 | 0.0636 | 0.3527 | 0.0017 | 1.6460 | 0.0991 |
| Total | 44 | | | | | | |
| Overall average | | 4.49 | 1.44 | 3.04 | 0.67 | 12.64 | 2.26 |
| CV (%) | | 17.07 | 17.50 | 19.54 | 6.17 | 10.14 | 14.14 |

*=Significant in 5% probability by F test; $^{ns}$=Not significant; DF=degrees of freedom; CV=coefficient of variation; BP=biological productivity; LP=leaf productivity; RP=root productivity; CI=crop index; LR=length of root; RD=root diameter.

In Table 4 of averages in 2019 (sowing in February), Brasília Nina was the only cultivar that presented biological, leaf and root productivity and the highest diameter of the edible product, the same happening in 2020, in all analyzed variables. In 2020 (sowing in March), all cultivars showed similar biological and root productivity, diameter and length of the edible structure. In these conditions, most cultivars stood out “a” in all analyzed variables, with the exception of Danvers, with inferior leaf productivity and Nantes in leaf productivity and harvest index. On the other hand, analyzing the structure of economic importance, all of them showed potential for cultivation when under milder conditions. The aspects linked to leaf productivity, although they seem unimportant, have an aspect of returning to the soil for decomposition and release of nutrients to the agro-ecological production system, taking advantage of the biological structure in all aspects.

The results presented in Table 4 raise the hypothesis of greater stability in the production of Brasília Nina cultivar when compared to the others in growing conditions with warmer temperatures. This condition reports the possible presence of alleles that indicate greater capacity to withstand higher temperature environments, a characteristic sought by breeding programs, indicating potential use in crossing blocks. On the other hand, the possibility of using the genetic variability available in these cultivars to recommend agro-ecological cultivation is evident, as long as the sowing time is observed, providing milder conditions for cultivation. Vieira et al. (1999) mention that mild temperatures from 10 to 15°C favor root elongation and temperatures above 21°C stimulate the formation of short roots, resulting in lower productivity. The average Brazilian productivity of carrots is approximately 29 t $ha^{-1}$ (Resende & Braga, 2014) with variations due to weather and soil conditions in different producing regions, as well as the characteristic of the cultivars used in each location. In this study, productivity values close to the national average were only possible in 2020, by sowing in March, confirming the need to provide milder temperatures in the cultivation cycle. In studies with carrot cultivars conducted in an agro-ecological based system, Paulus et al. (2012) observed root productivity around 32 t $ha^{-1}$ for cultivar Esplanada and 29 t $ha^{-1}$ for cultivar Nantes. Danvers reached productivity around 22 t $ha^{-1}$ of roots, similar to cultivar Brasília, with 20 t $ha^{-1}$. The productivity of the cultivars evaluated by the authors of the research were superior to the results obtained in this study, with the exception of the cultivar Brasília Nina, with productivity around 22 t $ha^{-1}$ of roots in 2019 and 2020, and Brasília Calibrada Média in 2020, with productivity of around 22 t $ha^{-1}$ of roots in 2019 and 2020, 3.66 kg $m^{-2}$, representing 29 t $ha^{-1}$ (Table 4).

**Table 4.** Average of carrot productivity indicators for various cultivars.

| Cultivars | BP (kg $m^{-2}$) | LP (kg $m^{-2}$) | RP (kg $m^{-2}$) | CI (kg $kg^{-1}$) | LR (cm) | RD (cm) |
|---|---|---|---|---|---|---|
| | 2019 | | | | | |
| Brasília Calibrada Média | 3.41 b | 1.51 b | 1.90 b | 0.55 a | 13.22 a | 2.66 b |
| Brasília Nina | 5.13 a | 2.27 a | 2.88 a | 0.56 a | 12.44 b | 2.93 a |
| Danvers | 2.90 b | 1.56 a | 1.42 b | 0.49 b | 11.56 b | 2.37 b |
| Esplanada | 3.48 b | 1.51 b | 1.96 b | 0.56 a | 14.44 a | 2.49 b |
| Nantes | 3.91 b | 1.67 a | 2.24 b | 0.57 a | 14.33 a | 2.56 b |
| Overall average | 3.77 | 1.70 | 2.08 | 0.55 | 13.20 | 2.60 |
| | 2020 | | | | | |
| Brasília Calibrada Média | 5.28 a | 1.62 a | 3.66 a | 0.70 a | 12.89 a | 2.32 a |
| Brasília Nina | 4.57 a | 1.73 a | 2.82 a | 0.69 a | 11.67 a | 2.21 a |
| Danvers | 3.89 a | 1.18 b | 2.71 a | 0.69 a | 12.11 a | 2.32 a |
| Esplanada | 4.68 a | 1.42 a | 3.26 a | 0.68 a | 14.22 a | 2.15 a |
| Nantes | 4.00 a | 1.26 b | 2.74 a | 0.61 b | 12.33 a | 2.13 a |
| Overall average | 4.48 | 1.44 | 3.04 | 0.67 | 12.64 | 2.23 |

BP=biological productivity; LP=leaf productivity; RP=root productivity; CI=crop index; LR=length of root; RD=root diameter. Averages followed by the same letter in the column constitute a statistically homogeneous group by the Scott and Knott test at 5% probability of error.

In Table 5, with average and regression of carrot productivity indicators in 2019, the harvest index and length and diameter of roots were not changed by the different spacing between rows. This year, the biological, leaf and root productivity showed higher expression results in the smallest spacing. In these variables, the results obtained between 15 and 20 cm between lines did not differ from each other, with the exception of biological productivity, with a lower value in the larger spacing. It is noteworthy that the trends of expression reduction were confirmed by the negative linear behavior and significant angular coefficient (bix) for biological, leaf and root productivity. In 2020 (Table 5), effective results of the effects of spacing between rows were also obtained only for biological, leaf and root productivity, with negative linearity confirmed by the significance of the angular coefficient. In this agricultural year, there were more pronounced effects in the reduction of the variables by the increase in each spacing point, configuring the separation of average into three distinct classes.

**Table 5.** Average and regressions of carrot productivity indicators in 2019 and 2020.

| Variable (y) | Spacing (cm) | Average | Equation y=a±bx | $b_ix$ | R² |
|---|---|---|---|---|---|
| | 2019 | | | | |
| | 10 | 4.81 a | | | |
| BP (kg m$^{-2}$) | 15 | 3.43 b | 6.41 - 0.176x | * | 90 |
| | 20 | 3.06 c | | | |
| | 10 | 2.21 a | | | |
| LP (kg m$^{-2}$) | 15 | 1.52 b | 2.93 - 0.081x | * | 86 |
| | 20 | 1.39 b | | | |
| | 10 | 2.63 a | | | |
| RP (kg m$^{-2}$) | 15 | 1.91 b | 3.48 - 0.093x | * | 90 |
| | 20 | 1.70 b | | | |
| | 10 | 0.54 a | | | |
| CI (kg kg$^{-1}$) | 15 | 0.55 a | 0.53 - 0.001x | ns | - |
| | 20 | 0.56 a | | | |
| | 10 | 12.53 a | | | |
| LR (cm) | 15 | 13.33 a | 11.40 + 0.120x | ns | - |
| | 20 | 13.73 a | | | |
| | 10 | 2.45 a | | | |
| RD (cm) | 15 | 2.68 a | 2.26 + 0.023x | ns | - |
| | 20 | 2.68 a | | | |
| | 2020 | | | | |
| | 10 | 5.53 a | | | |
| BP (kg m$^{-2}$) | 15 | 4.49 b | 7.61 - 0.2083x | * | 99 |
| | 20 | 3.44 c | | | |
| | 10 | 1.80 a | | | |
| LP (kg m$^{-2}$) | 15 | 1.41 b | 2.47 - 0.0687x | * | 99 |
| | 20 | 1.11 c | | | |
| | 10 | 3.73 a | | | |
| RP (kg m$^{-2}$) | 15 | 3.06 b | 5.14 - 0.1398x | * | 99 |
| | 20 | 2.33 c | | | |
| | 10 | 0.67 a | | | |
| CI (kg kg$^{-1}$) | 15 | 0.68 a | 0.68 - 0.001x | ns | - |
| | 20 | 0.67 a | | | |
| | 10 | 12.33 a | | | |
| LR (cm) | 15 | 12.87 a | 12.04 + 0.0400x | ns | - |
| | 20 | 12.73 a | | | |
| | 10 | 2.22 a | | | |
| RD (cm) | 15 | 2.21 a | 2.18 + 0.0027x | ns | - |
| | 20 | 2.25 a | | | |

*=Significant at 5% probability; ns=Not significant; BP=biological productivity; LP=leaf productivity; RP=root productivity; CI=crop index; LR=length of root; RD=root diameter; IS=indicated spacing. Averages followed by the same letter in the column constitute a statistically homogeneous group by the Scott and Knott test at 5% probability of error.

From the results obtained from the carrot productivity and quality indicators, it can be seen that although the smaller spacing between rows promotes an increase in root productivity, it does not provide an improvement in the commercial quality of the product in the same direction. The spacing between 15 cm between lines shows technical aspects of management and commercial quality that best fit for recommendation, especially when dealing with agro-ecological based management.

The quality of carrot roots depends on the genetic characteristics of the cultivars, the environmental conditions during the growing season and during final storage, as well as the management techniques adopted during cultivation (Wszelaczyńska et al., 2019). This fact confirms the results found by Lopes et al. (2008), in which carrot productivity increases as population density increases, and it is directly related to the greater number of plants. On the other hand, it results in lower availability of photosynthetic radiation for leaves located in the lower part of the plant, causing self-shading and a reduction in the net photosynthetic rate, with a reduction in the size of roots (Lopes et al., 2008).

From the linear behavior obtained from the productivity variables, Table 6 shows the simulation of these variables using the spacing proposed in this study. In the year 2019 (Table 6), the simulation results presented ensure adequate productivities for the agro-ecological production system. As reported earlier, it is noteworthy that the year 2020 provided higher root productivity results, determining the main change in biological productivity. The analysis proves the possibility of carrying out carrot cultivation in smaller spacing between rows, as observed for 15 cm, different from the recommendation that has been indicating 20 cm. The results presented allow for greater efficiency in the use of the area, ensuring satisfactory productivities allied to obtaining higher quality roots produced in an agro-ecological based management system.

**Table 6.** Simulation of carrot productivity indicators in 2019 and 2020.

| Year | Variable | Equation | Line spacing (cm) | $y_E$ (kg m$^{-2}$) |
|---|---|---|---|---|
| 2019 | BP | 6.41 - 0.176x | 15 | 3.77 |
| | LP | 2.93 - 0.081x | 15 | 1.72 |
| | RP | 3.48 - 0.093x | 15 | 2.08 |
| 2020 | BP | 7.61 - 0.2083x | 15 | 4.48 |
| | LP | 2.47 - 0.0687x | 15 | 1.44 |
| | RP | 5.14 - 0.1398x | 15 | 3.04 |

BP=biological productivity; LP=leaf productivity; RP=root productivity; $y_E$=estimated yield.

Modern agriculture has increasingly sought to maximize available resources through more sustainable forms of production, aiming not only to increase productivity, but also to seek quality food (Gomes et al., 2020). Thus, the increased awareness and concerns about the environmental and health impacts of the use of synthetic chemicals (fertilizers, pesticides…). In agriculture, they have been the main drivers of consumer demand for organic food (Anup et al., 2017). Thus, due to the greater degree of knowledge about the quality of products, consumers have been giving preference to fresh products, of smaller size and greater nutritional value (Hoppu et al., 2020). In this context, to increase the total root productivity and the number of carrots in marketable diameters, the control of average plant spacing directly influences these indicators, as demonstrated and confirmed by the results of the research presented.

## CONCLUSIONS

The Brasília Nina carrot cultivar shows high performance on root yield and quality, mainly in the 15 cm spacing between rows in an agro-ecological system.

The production of carrot roots with quality and free from toxic contaminants, contributes to the valorization of the product for commercialization and production of food with greater sustainability and food safety.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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