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Yield and quality of carrot cultivars related to the harvest time

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ABSTRACT

The knowledge about harvest time in carrots is important to determine the moment when the farmer will be able to obtain higher yield and quality of roots. Thus, this work aimed to verify the moment of harvest, aiming to maximize yield and the quality of roots. From November 2018 to March 2019, three cultivars, Brasília, BRS Planalto and HX4098 were evaluated in Brasília-DF in DBC design with three replications, in a split plot scheme, in which the treatments of the subplots were the harvest times at 80, 90, 100, 110 and 120 days after sowing (DAS). The experiment was installed on November 20, 2018, in 1 m^2 useful area seedbeds. Sowing was done manually, in transverse grooves, with double spacing rows 10 x 20 cm, and 5 cm spacing between plants. Cultural treatments were those adopted for the carrot culture for the Brazilian Cerrado biome. At harvest, the total mass, non-commercial and commercial roots, number of roots of each class, average diameter and length of commercial roots and °Brix were evaluated. The best harvest time to obtain maximum yield is close to 110 DAS, with a small reduction in °Brix after 90 DAS.

Keywords: *Daucus carota*, root yield, °Brix, root length, root diameter.

RESUMO

Produtividade e qualidade de cultivares de cenoura em função da época de colheita

O conhecimento sobre a época de colheita em cenoura é importante para determinar o momento em que o produtor poderá obter maiores produtividade e qualidade de raízes. Assim, este trabalho teve como objetivo verificar o momento da colheita, visando maximizar o rendimento e a qualidade de raízes. Entre novembro de 2018 a março de 2019, três cultivares, Brasília, BRS Planalto e HX4098 foram avaliadas em Brasília-DF em delineamentos DBC com três repetições, com esquema de parcela subdividida, em que os tratamentos das sub-parcelas foram as épocas de colheita aos 80, 90, 100, 110 e 120 dias após a semeadura (DAS). O experimento foi instalado em 20/11/2018, em canteiros de 1 m^2 de área útil. A semeadura foi feita manualmente, em sulcos transversais, com espaçamento duplo de 10 x 20 cm, e espaçamento entre plantas de 5 cm. Os tratos culturais foram os adotados para a cultura da cenoura para o cerrado brasileiro. Na colheita, foram avaliadas as massa total, do refugo e comercial de raízes, número de raízes de cada classe, diâmetro e comprimento médios de raízes comerciais e °Brix. Verificou-se que a melhor época de colheita para obter o máximo rendimento é próximo aos 110 DAS, com pequena redução no °Brix a partir dos 90 DAS.

Palavras-chave: *Daucus carota*, rendimento de raízes, °Brix, comprimento de raízes, diâmetro de raízes.

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Carrots are one of the main vegetables grown and consumed in Brazil. It is estimated that more than 480 thousand tons are produced annually in an area of more than 13 thousand ha. The main producing regions are Alto do Paranaíba Mineiro with more than 50% of the country's production, followed by the regions of Marilândia do Sul-PR, Caxias do Sul-RS, Cristalina-GO and Irecê-BA (IBGE, 2017).

The best time to harvest the carrot depends on the cultivar, sowing time and handling. Usually the harvest is carried out between 80 to 120 days after sowing (DAS) (Vieira *et al*., 2008), and this factor directly interferes in the productivity and quality of the carrot roots.

According to Kjellenberg *et al*. (2016), physiologically, the maturity of the carrot occurs when the carotenoids, as well as the sugars, reached their maximum concentrations. However, increasing the period from sowing to harvest, there is a tendency to increase root yield (Simões *et al*., 2010; Lana, 2012). This fact explains why producers delay harvests in order to increase productivity per unit area.

Sasaki (2015) proposed the classification of carrots in relation to root length in classes 10 (≥10 to <14cm), 14 (≥14 to <18cm), 18 (≥18 to <22cm), 22 (≥22 to <26cm) and 26 (>26 cm). Being that farmers usually get the highest remuneration with the roots of class 18 (≥18 to <22cm) or "caixa 3A", as they better meet consumer preferences; while very small roots, below 10 cm in length, or very large, above 26 cm in length, are not desirable, as they are less valued by consumers (Silva *et al*., 2011).

In relation to other characteristics such as shape and appearance, the preference of Brazilian consumers is for roots with a diameter from three to five cm, intense orange color and little differentiated between xylem and phloem, and without external defects

such as cracks, forked or green/purple shoulder (Lana & Vieira, 2000).

Regarding quality, a measure that is easy to evaluate, and that can be used in practice by farmers, is that of total soluble solids (Gomes Junior *et al*., 2001). When represented by °Brix, the total soluble solids correspond to the percentage of solids dissolved in a solution. In fruits and vegetables, total soluble solids are predominantly composed of sugars, in addition to pectins, organic acids and amino acids, and these, by influencing flavor, become important quality factors (Magwara & Opara, 2015). Studies show that total soluble solids can vary according to cultivar, fertilization, sowing density, irrigation, climate, and maturation stage (Lima Junior *et al*., 2012; Figueiredo Neto *et al*., 2010; Kleynhenz & Bumgarner, 2012).

Thus, in this study we aimed to verify when the harvest should be carried out, aiming to maximize the yield and the quality of carrot roots.

MATERIAL AND METHODS

The experiment was carried out in the Embrapa Vegetable experimental area (15°55'49"S; 48°08'29"W, 1009 m altitude), located in Brasília-DF on November 28, 2018. In the period of the experiment, the average temperature was 22.21±0.56°C and total precipitation of 1,042 mm. The region's climate is Aw, Tropical Climate with a dry season in winter, according to Köppen-Geiger. The soil in the experimental area is classified as a clayey Oxisol with a clay texture.

For sowing, the area was under fallow with carrot residues from the previous crop year, which were desiccated with non-selective herbicide (glyphosate in 2.85 kg a.i. ha^{-1} dosage) and incorporated in the plowing operation that occurred 60 days before sowing. One week before sowing, the soil was harrowed with a tandem disc and on the day of sowing the seedbeds were made with the bed shaper.

The soil analysis, performed three months before sowing, showed the following values: pH= 6.0, P= 12.0; K= 399.0; Na= 41.0, organic matter = 267.0; B= 0.18; Cu= 3.30; Fe= 57.2; Mn= 69.7; Zn= 8.1 and S= 2.7; all in mg dm^{-3}, except pH. Still Ca= 3.3, Mg= 1.5, Al= 0.0; H+Al = 3.7, all in cmolc dm^{-3}. Thus, limestone was not applied, and fertilization was carried out based on soil analysis of the commercial formula 04-14-08 (NPK) in the amount of 1,300 kg ha^{-1} (52 kg ha^{-1} N, 182 kg ha^{-1} P_2O_5 and 104 kg ha^{-1} K_2O) according to Ribeiro *et al*. (1999).

The experimental design was a randomized block with three replications in a 3 x 5 split plot scheme, in which the effects of cultivars were on the plots (Brasília, BRS Planalto and HX4098) and on the subplots, the effects of the harvest times (80, 90, 100, 110 and 120 days after sowing, DAS). The experimental plot consisted of 1 m^2 useful area.

Sowing was done manually in furrows across the bed, in double spacing 10 x 20 cm, with 10 cm between single rows and 20 cm between double rows, totaling a plant population of around 800 thousand plants per hectare after thinning. Weed control was carried out with the application of the herbicide linuron at 0.99 L of a.i. ha^{-1} four days after sowing. In the period after germination, weeding was performed manually.

Irrigation was carried out by conventional spraying, to meet the crop's demand in periods of scarcity of rain. The topdressing manuring was carried out right after thinning, at 30 DAS, in the dosage of 400 kg ha^{-1} of ammonium sulfate (80 kg ha^{-1} N) according to Ribeiro *et al*. (1999).

From 60 DAS, weekly, the fungicide Difenoconazole was applied at a dose of 0.15 kg a.i. ha^{-1}. The other handlings were those normally used for the cultivation of carrots in the Brazilian Cerrado region (Filgueira, 2008).

After each harvest, performed at 80, 90, 100, 110 and 120 DAS, evaluations of the following characters were carried out: total root mass (TRM, t ha^{-1}), by weighing with digital scale all roots harvested in the plot; marketable root mass (MRM, t ha^{-1}), by weighing the roots with marketable standard; non-marketable root mass (NRM, t ha^{-1}), obtained by the difference between TRM and MRM; number of marketable roots (NMR, x 10^3 ha^{-1}) by counting roots with marketable standard; number of total roots (NTR, ha^{-1} x 10^3) by counting all roots harvested in the plot; number of non-marketable roots (NNR, ha^{-1} x 10^3) by the difference between NTR and NMR.

Roots without external defects such as cracks, forked or green shoulder were considered marketable; with a diameter between three and five cm and a length from 10 to 26 cm. The conversion to hectare was calculated considering the effective width of the 1.5 m; 1 m from the seedbed, plus 0.5 m from the spaces formed by the spaces between seedbeds.

Twenty marketable roots per plot were taken at random to obtain the average root diameter (ARD, measurements taken in the middle portion of the root, with a digital caliper, in cm) and average root length (ARL, performed with a graduated ruler, in cm). Then, a sample of approximately 20 grams of 20 roots from each plot was grated, mixed, and a drop of juice was removed to assess the content of total soluble solids using a digital refractometer (Atago Pocket) with results expressed in °Brix.

The data were tested for the assumptions of the analysis of variance and the analyzes of variance were performed, as well the Tukey's means comparison test (5%), and regression analyzes for the quantitative treatments (DAS). All analyzes were performed using the Genes computational application (Cruz, 2013).

RESULTS AND DISCUSSION

There were significant differences by the F test ($P<0.05$) between cultivars (C) and between harvest times (HT) for all characters. However, there were no significant differences in the C x HT interaction for any evaluated character (data not shown).

For total root mass (TRM), BRS Planalto (65.69 t ha^{-1}) was superior to the hybrid HX 4098 (56.57 t ha^{-1}) by the Tukey test at 5% probability, whereas 'Brasília' (57.22 t ha^{-1}) was not different from HX4098 and BRS Planalto (Table 1). For number of marketable roots

(NMR) BRS Planalto (370.67 x10^3 ha^{-1}) and 'Brasília' (347.56 x10^3 ha^{-1}) were higher than HX4098 (253.33 x10^3 ha^{-1}).

For marketable root mass (MRM) BRS Planalto (39.26 t ha^{-1}) was higher than 'Brasília' (31.14 t ha^{-1}), however HX4098 (34.69 t ha^{-1}) did not differ from BRS Planalto and 'Brasília'. For number of non-marketable roots (NNR) BRS Planalto (278.39 x10^3 ha^{-1}) and 'Brasília' (300.87 x10^3 ha^{-1}) were higher than HX4098 (113.14 x10^3 ha^{-1}). There were no differences between the three cultivars for non-marketable root mass (NRM), showing that although the hybrid HX 4098 had lower TRM than the open-pollinated cultivars, it presented MRM equivalent to BRS Planalto by the lowest NRM. As emphasized by Carvalho *et al*. (2015) and Pereira *et al*. (2015), the heterosis of carrot hybrids is due to the higher proportion of marketable roots, as these tend to have more uniform roots than open pollinated cultivars.

Regarding the two open pollination cultivars, Carvalho *et al*. (2015), measuring MRM at 100 DAS, found superior yield of commercial roots from BRS Planalto over Brasília, with values of 25.81 and 16.06 t ha^{-1}, respectively. Likewise, Carvalho *et al*. (2017), in the evaluation in 20 environments, found an average MRM value of 34.54 t ha^{-1} for 'Brasília' and 35.95 t ha^{-1} for BRS Planalto. Pereira *et al*. (2015) evaluated the cultivar BRS Planalto in summer conditions in Brasília-DF, and found a high MRM (58.07 t ha^{-1}), roots with an average mass of 109.73 g, with an average length of 17.43 cm and diameter of three cm.

It is observed that in relation to ARL, 'Brasília' (18.47 cm) and 'BRS Planalto' (18.41 cm) presented greater length than 'HX4098' (17.25 cm), which, on the other hand, presents greater ARD (HX4098 = 3.26 cm) if compared to 'Brasília' (3.03 cm) and 'BRS Planalto' (3.08 cm).

ºBrix was superior for cultivar HX4098 (7.80) compared to 'Brasília' (6.93) and 'BRS Planalto' (6.53). This fact can be attributed to the possible genetic constitution of a hybrid, which probably has germplasm in its genealogy with a high degree of breeding for root quality (Carvalho *et al*., 2015).

Regarding °Brix, several factors can influence the expression of this characteristic. In this sense, Alves *et al*. (2010) found a value of 8.63°Brix for the cultivar Brasília harvested at 100 DAS, and Paulus *et al*. (2012), harvest at 85 DAS, found a value of 8.30°Brix also for 'Brasília'. Figueiredo Neto *et al*. (2010) found for this same cultivar, harvested at 92 DAS, an average value of 6.24°Brix; with a variation of 5.53 to 7.20°Brix depending on the type of fertilization used; and Lima Júnior *et al*. (2012) found significant effects of the interference of the amount of water used in irrigation at °Brix.

The effects of harvesting times were represented using regression curves (Figures 1 and 2). For MRM it appears that the maximum yield was obtained around the harvest performed at 110 DAS, with 109 DAS for 'Brasília' (32.8 t ha^{-1}), 111 DAS for 'HX4098' (49.3 t ha^{-1}) and 110 DAS for 'BRS Planalto' (49.5 t ha^{-1}) (Figure 1A).

NMR decreased substantially with later harvests, until reaching their minimum in 120 DAS for 'Brasília' (205 roots x10^3 ha^{-1}), in 107 DAS for 'HX4098' (203 roots x10^3 ha^{-1}) and 111 DAS for 'BRS Planalto' (160 roots x10^3 ha^{-1}) (Figure 1B); and as the harvest time was delayed, the opposite was found for the NMR, with the highest values at 120 DAS for 'Brasília' (374 x10^3 ha^{-1}); earlier, at 104 DAS for 'HX4098', (378 x10^3 ha^{-1}); while for 'BRS Planalto' the largest NMR was achieved at 111 DAS (419 x10^3 ha^{-1}) (Figure 1D).

There was a greater increase for TRM between 90 and 110 DAS for the three cultivars, culminating in a higher value at 113 DAS for 'Brasília' (72.5 t ha^{-1}), 112 DAS for 'HX4098' (81.0 t ha^{-1}) and 111 DAS for 'BRS Planalto' (74.5 t ha^{-1}) (Figure 1C).

NMR presented estimates of minimum values for 'Brasília' (9.1 t ha^{-1}), 'HX4098' (11.7 t ha^{-1}) and 'BRS Planalto' (22.6 t ha^{-1}), for harvests at 89, 87 and 94 DAS, respectively (Figure 2A).

The increase in MRM with the advance in the cycle is also reported by Lana (2012), in the evaluation of spacing and harvest times in carrots for the production of baby carrots.

On the other hand, the ARL increased until reaching the maximum at 109 DAS for 'HX4098' (16.91 cm), 106 DAS for 'Brasília' (19.16 cm), and at 95 DAS for 'BRS Planalto' (17.85 cm). The ARD, however, decreased after about 100 DAS, since, after that period, a larger amount of roots with a larger diameter began to present defects such as cracks, rot, deformation, green/purple shoulder, withered or injured roots by the pest attack, with a 13% increase in losses (data not shown), predominantly due to the disposal of very thick roots.

Table 1. Tukey's means test between three carrot cultivars, averaging different harvest periods (80, 90, 100, 110 and 120 days after sowing). Brasília, Embrapa Hortaliças, 2019.

Cultivars	TRM	NMR	MRM	NNR	NRM	ARL	ARD	ºBrix
BRS Planalto	65.69 a	370.67 a	39.26 a	278.39 a	25.40 a	18.41 a	3.08 b	6.53 b
Brasília	57.22 ab	347.56 a	31.14 b	300.87 a	23.66 a	18.47 a	3.03 b	6.93 b
HX-4098	56.57 b	253.33 b	34.69 ab	113.14 b	20.12 a	17.25 b	3.26 a	7.80 a
Means	59.83	323.85	35.03	230.80	23.06	18.05	3.12	7.09
CV (%)	16.08	20.02	10.20	12.97	16.16	5.50	3.51	8.17

TRM= total root mass (t ha^{-1}); NMR= number of marketable roots (x10^3 ha^{-1}); MRM= marketable root mass (t ha^{-1}); NNR= number of non-marketable roots (x10^3 ha^{-1}); NRM= non-marketable root mass (t ha^{-1}); ARL= Average root length (cm); ARD= average root diameter (cm). Means followed by different letters in the columns differed statistically by the Tukey test at 5%.

In the literature, the increase in yield at the end of the cycle occurs mainly due to the increase in the diameter of the roots, and not so much in length (Simões *et al*., 2010; Vieira *et al*., 2012). Due to the fact that the roots initially develop more in length, with later greater growth in diameter (Silva *et al*., 2009; Vieira *et al*., 2012), however this fact cannot be standardized for ARD, in which the delay in harvesting considerably increases the number of thick roots discarded by serious defects.

Total soluble solids, represented by °Brix, were highest at 91 days for 'Brasília' (6.6°Brix), at 89 days for 'HX4098' (7.2°Brix) and 91 days for 'BRS Planalto' (6.4°Brix) (Figure 2C).

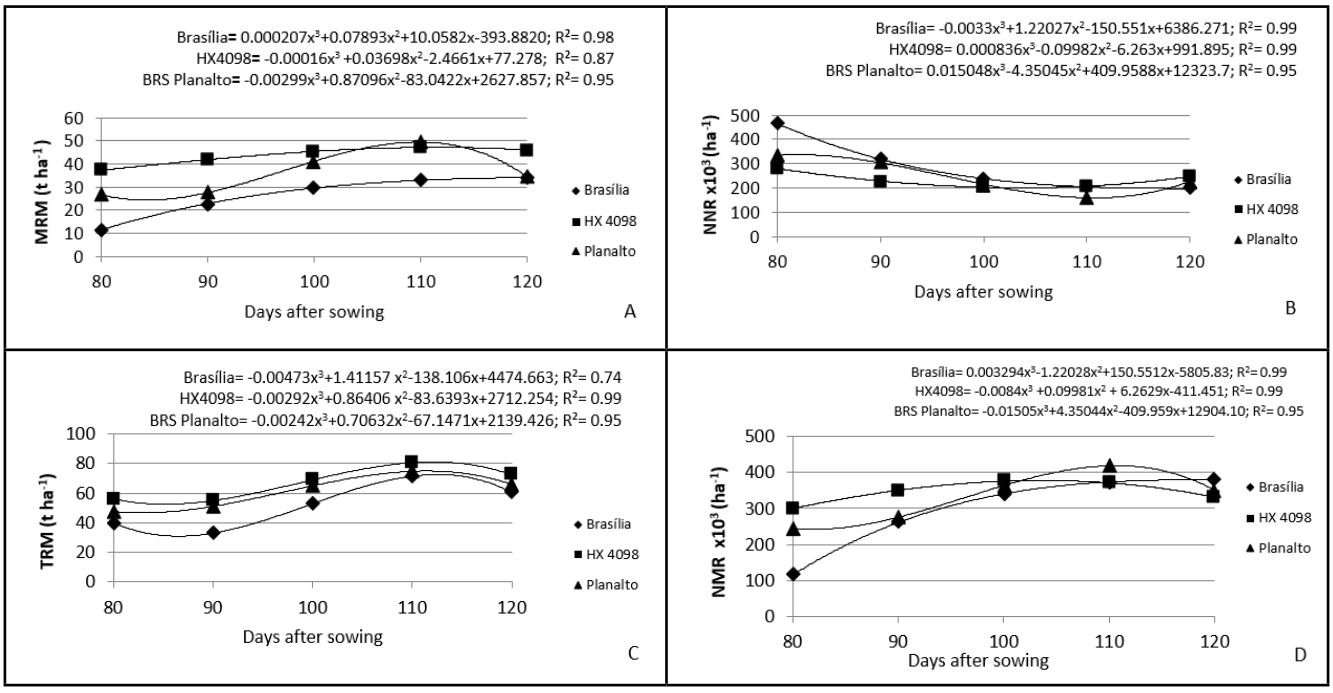

Figure 1. Regression analysis for three carrot cultivars evaluated for marketable root mass (MRM), number of non-marketable roots (NNR); total root mass (TRM) and number of marketable roots (NMR) due to different harvest times in the Federal District. Brasília, Embrapa Hortaliças, 2019.

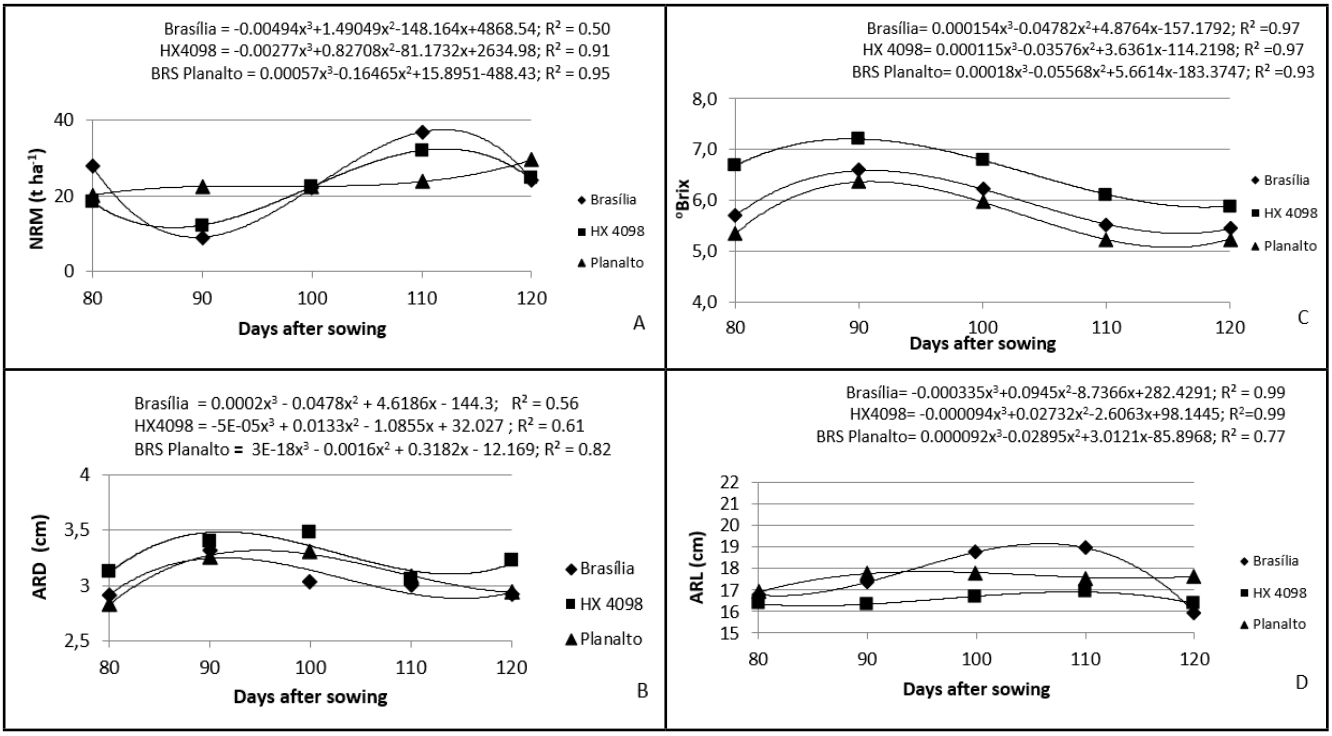

Figure 2. Regression analysis for three carrot cultivars evaluated for non-marketable root mass (NRM), average root diameter (ARD), °Brix and average root length (ARL) due to different harvest times in the Federal District. Brasília, Embrapa Hortaliças, 2019.

Therefore, there is an indication that in this period the roots had the best quality in relation to the sugar content, and that this value decreased too much with the delay in the harvest period.

About TSS, the peak concentration coincides with the accumulation curve for this compound described by Rubatzky *et al*. (1999). The change in the total sugar content after 90 DAS, with a reduction after this period, can occur, among other factors, by the reduction of the leaf area after this period, which affected the production and accumulation of secondary compounds, such as sugars. Another factor that may have contributed to this reduction in ºBrix levels may be the increase in the values of the component production characters (MRT, MRC and MRR) after 90 DAS, with the plants entering the senescence stage, resulting in a greater accumulation of fresh mass at the expense of ºBrix levels.

In assessing the accumulation of dry matter from 50 DAS, Simões *et al*. (2010) found that there were no significant differences for the cultivar Forto with the harvest time from 50 DAS to 106 DAS, that is, in periods closer to harvest, the ºBrix content remains constant, despite the increasing root size. Gajewski *et al*. (2009) evaluating eight carrot cultivars in Poland, with cultivars suitable for that country, described increasing values of ºBrix with successive harvest periods ranging from 40 to 125 DAS. In view of these results, it was found that the best harvest time to maximize the yield of commercial roots, both for the open pollination cultivars 'BRS Planalto' and 'Brasília', and for the hybrid 'HX4098', is around 110 DAS, although there is a small reduction in the ºBrix content after 90 DAS.

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