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CROP PRODUCTION

Experimental plan for carrot culture

Darlei Michalski Lambrecht[1*] Jaqueline Sgarbossa[1] Maria Inês Diel[2] Alessandro Dal'Col Lúcio[1] Lucas Encarnação Marques[1] Iara Cristina Raddatz[1] André Luís Tischler[1] Francieli de Lima Tartaglia[1] Lana Bruna de Oliveira Engers[1] Ingrid Rodrigues Soncini[1] Marcielli Matiazzi Kuhn[1]

[1]Departamento de Fitotecnia, Universidade Federal de Santa Maria (UFSM), 97105-900, Santa Maria, RS, Brasil. E-mail: darleilambrecht@gmail.com.
[*]Corresponding author.
[2]Universidade Federal de Santa Maria (UFSM), Cachoeira do Sul, RS, Brasil.

ABSTRACT: The carrot culture stands out on the world stage due to its nutritional characteristics and economic importance, an aspect that demands the constant development of research aiming greater productivity. Thus, this study proposed an experimental plan, determining the estimates of plot size, sample size, and number of repetitions, with the purpose of increasing the precision and reliability of the results of the experiments with the carrot crop. Six uniformity trials were conducted, using three cultivars in two growing seasons (Season: 2019 and 2021). Each plant was considered a basic experimental unit and in each BEU, the variables shoot height, root length, shoot fresh mass, root fresh mass, and root diameter were measured. The size of the plot, sample, and the number of repetitions was estimated by the method of maximum curvature of the coefficient of variation. The results recommend that for experiments with the carrot crop, plots with twelve plants should be used. For a sampling of carrot plants in the plot, samples of eleven plants must be used in the direction of the row, considering a semi-amplitude of the confidence interval (D%) equal to 20% of the mean, with a confidence level of 95%. For a minimum significant difference in the Tukey test expressed as a percentage of the 50% mean, plots of twelve plants per crop row, with eight replicates, are recommended.
Key words: *Daucus carota* L., plot size, sample size, number of replicates.

Plano experimental para a cultura da cenoura

RESUMO: A cultura da cenoura se destaca no cenário mundial por suas características nutricionais e importância econômica, aspecto que demanda o constante desenvolvimento de pesquisas visando maior produtividade. Assim, o objetivo deste trabalho foi propor um plano experimental, determinando as estimativas de tamanho de parcela, tamanho de amostra e número de repetições, com a finalidade de aumentar a precisão e confiabilidade dos resultados dos experimentos com a cultura da cenoura. Foram conduzidos seis ensaios de uniformidade, utilizando três cultivares em duas safras (Safra: 2019 e 2021). Cada planta foi considerada uma unidade experimental básica e em cada BEU foram medidas as variáveis altura da parte aérea, comprimento da raiz, massa fresca da parte aérea, massa fresca da raiz e diâmetro da raiz. O tamanho da parcela, da amostra e o número de repetições foram estimados pelo método da máxima curvatura do coeficiente de variação. Os resultados recomendam que para experimentos com a cultura da cenoura sejam utilizadas parcelas com doze plantas. Para amostragem de plantas de cenoura na parcela, devem ser utilizadas amostras de onze plantas no sentido da linha, considerando uma semi-amplitude do intervalo de confiança (D%) igual a 20% da média, com nível de confiança de 95%. Para uma diferença mínima significativa no teste de Tukey expressa em porcentagem da média de 50%, recomendam-se parcelas de doze plantas por fileira de cultivo, com oito repetições.
Palavras-chave: *Daucuscarota* L., tamanho da parcela, tamanho da amostra, número de repetições.

INTRODUCTION

The carrot (*Daucus carota* L.) is an annual vegetable, with high nutritional and economic importance, it has versatility, and agronomic and ecological adaptability, in addition to being important for the diversification of agricultural production and for food security (QUE et al., 2019). According to the last survey carried out in 2021 by (FAO, 2023), global carrot production occupied 866.6 billion ha of cultivated area, with a production of 32.8 trillion tons, with the largest producers in the area (ha) being Asia (72%), Africa (14%), North and South America South (13%), Oceania (0.8%) and Europe (0.00003%), regarding production (tons), the main world producers are Asia (80%) and North and South America (11%) followed by Africa (7%), Oceania (1%) and Europe (0.00003%).

Due to the great economic and nutritional importance of carrots, it is essential that research be carried out, with the aim of obtaining new cultivation and management techniques, as well as developing and identifying new high-yield cultivars, combined with adaptability and production stability, with high tolerance to pests and diseases. For these recommendations to be reliable, it is important that researchers use concepts from agricultural experimentation to design and conduct their experiments (LAMBRECHT et al., 2022).

One of the fundamental concepts of agricultural experimentation is experimental planning. An adequate plot size, sample size, and

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number of repetitions should be recommended, so that the variability between plots is a result of the effect of their treatments, that the experimental error is reduced and, as a consequence, obtain- if high precision and reliability of the results (LÚCIO et al., 2020; LÚCIO & SARI, 2017).

There are several factors that influence experimental design, such as the size of the available experimental area, soil variability, plant variability, desired accuracy, and cost of materials and labor, and each factor must be carefully considered (LÚCIO & BENZ, 2017). Experimental variability can have a significant impact on the interpretation of experiment results, as it can make it difficult to detect significant differences between treatments tested.

In this way, small plot sizes, sample sizes, and number of repetitions may be suitable for experiments in which variability is low and the cost of materials and labor is high. But, it may not be suitable for experiments where variability is high, as the results may not be accurate enough to provide reliable information. Conversely, a large plot size, sample size, and number of repetitions may be more suitable for experiments where variability is high, as it provides greater accuracy of results. But, it may not be practical for experiments where the cost of materials and labor is high (KRYSCZUN et al., 2018; LÚCIO et al., 2020; TARTAGLIA et al., 2021).

In this sense, several researchers have already been carried out to estimate the plot size, sample size, and the number of repetitions for several vegetable crops such as lettuce (LÚCIO et al., 2011), eggplant (KRYSCZUN et al., 2018), cucumber (LÚCIO et al., 2020), pea (TARTAGLIA et al., 2021), and onion (LAMBRECHT et al., 2022). But, for the carrot culture, there are few research with this purpose, and, considering the importance of the culture, studies must be carried out in order to assist researchers in making decisions in their experiments. This study was proposed an experimental plan, indicating the estimates of plot size, sample size, and number of repetitions, with the purpose of increasing the precision and reliability of the results of experiments with the carrot crop.

MATERIALS AND METHODS

Site description and experimental design

The research was carried out with the results of six uniformity trials conducted in the experimental area of the Department of Plant Science at the Federal University of Santa Maria (29° 42' 23''S; 53° 43' 15'' W, and 95 m altitude), during the 2019 and 2021 agricultural years. According to the Köppen classification, the climate in the region is Cfa - temperate rainy, with well-distributed rainfall throughout the year and subtropical from a thermal point of view (ALVARES et al., 2013). The soil in the experimental area is classified as Argissolo Bruno-AcinzentadoAlíticoÚmbrico (Ultisol) (STRECK et al., 2018). Chemical fertilization was carried out according to the soil analysis and recommended based on the guidelines of the Liming and Fertilization Manual for the States of Rio Grande do Sul and Santa Catarina for the carrot crop (CQFS, 2016).

The sowing of the uniformity s was carried out at two different seasons. In the first season, three trials were conducted, with three carrot cultivars, being them: BRS Planalto Isla® (cultivar 1), AlvoradaCalibradaMédia Isla® (cultivar 2) e Suprema CalibradaMédia Isla® (cultivar 3), whose sowing took place on September 14, 2019, in seven beds of 5 m in length, with three rows of plants each, spaced 0.25 m apart and 0.10 m between plants. In the second season, three more uniformity trials were carried out, with three carrot cultivars, being them: BRS Planalto Isla® (cultivar 1), AlvoradaCalibradaMédia Isla® (cultivar 2) e Suprema CalibradaMédia Isla® (cultivar 3), whose sowing took place on November 5, 2021, in six beds of 5 m in length, with three rows of plants each, spaced 0.25 m apart and 0.10 m between plants.

The trial were harvested on December 13, 2019, and January 22, 2022, for seasons 1 and 2, respectively. Each plant was considered a basic experimental unit (BEU) and in each of the BUE the variables shoot height (SH, in cm) and root length (RL, in cm) was measured, both measured with the aid of a ruler graduated. The variables shoot fresh mass (SFM in g) and root fresh mass (RFM, in g), were also quantified with the aid of a precision analytical balance and the root diameter variable (RD, in cm), measured with a Pachymeter Vernier Caliper 0.5 mm to 150 mm.

Statistical analyzes

Test of homogeneity of variances

A test of homogeneity of variances was carried out between the rows of cultivation for each bed, variable, and cultivar, through the test of homogeneity of variances proposed by (LEVENE, 1960), by Eq. 1:

$$W = \frac{(N-k)}{(k-1)} \cdot \frac{\sum_{i=1}^{k} N_i \,(Z_{i.} - Z_{..})^2}{\sum_{i=1}^{k}\sum_{j=1}^{N_i} (N_{ij} - Z_{i.})^2} \quad (1)$$

Where k is the number of different groups to which the sampled cases belong, N_i is the number of cases $i^{\,o}$ group, N is the total number of cases in all groups, Z_{ij} is the value of the measured variable for the j^{o} case of i^{o} group, estimated by Eq. 2.

$$Z_{ij} = \begin{cases} |Y_{ij} - \bar{Y}_{i.}|, \bar{Y}_{i.} \text{ It is the mean of the group} i \\ |Y_{ij} - \tilde{Y}_{i.}|, \tilde{Y}_{i.} \text{ It is a median of the group} i \end{cases} \quad (2)$$

Plot size estimation

The size of each plot (number of plants) was calculated for each crop line using the maximum curvature of variance method proposed by (PARANAÍBA, 2009), by Eq. 3:

$$\widehat{X_0} = \frac{10\sqrt[3]{2(1-\hat{\rho}^2)s^2\bar{Y}}}{\bar{Y}} \quad (3)$$

Where, $\hat{X}_0$: is the proper plot size, s^2: is the varietal variance in each environment and each year of cultivation, $\bar{Y}$: is the average of the BEU of the cultivar, $\hat{\rho}$: is the first-order spatial autocorrelation, estimated by Eq. 4:

$$\rho = \frac{\sum_{i=1}^{n}(\hat{\varepsilon_i} - \bar{\varepsilon})(\hat{\varepsilon}_{i-1}\varepsilon)}{\sum_{i-1}^{rc}(\hat{\varepsilon_i} - \bar{\varepsilon})^2} \quad (4)$$

Where $\hat{\mathcal{E}}$: is the experimental error of each observation i BEU and, $\bar{\mathcal{E}}$: is the mean experimental error. Being experimental error estimated by Eq. 5:

$$\varepsilon_i = \rho\varepsilon_i - 1 + U_i \quad (5)$$

Where ρ are the first-order spatial autocorrelation coefficients, U_i are the "pure" experimental errors, independent of $U_{i\sim N(0,\sigma^2)}$.

Sample size estimate

The estimation of the sample size (number of plants) of each of the rows of cultivation was carried out using the methodology proposed by (COCHRAN, 1977), by Eq. 6:

$$n = \frac{t^2_{\propto/2}(CV\%)^2}{(D\%)^2} \quad (6)$$

Where n is the sample size (in m^2), $t^2_{\alpha/2}$ is the Student's t table value with n-1 degrees of freedom at 5% error probability, CV% is the coefficient of variation of the variable considered, calculated according to Eq. 7:

$$CV\% = \frac{100\sqrt{s^2}}{\bar{X}} \quad (7)$$

Where s^2 is the sample variance, $\bar{x}$ is the mean of the variable and D% is the semi-amplitude of the mean confidence interval (D% = 5, 10, 15 e 20). The corrections for the finite population were performed according to the recommendations of (COCHRAN, 1977).For this, applied Eq. 8:

$$nc = \frac{n}{1 + \frac{n}{N}} \quad (8)$$

On what nc is the adjusted sample size, N is the population size of each crop row and, n is the sample size for an infinite population.

Estimate of the number of repetitions

To estimate the number of repetitions, the minimum significant difference (d) of the Tukey test was used, expressed as a percentage of the average of the test by Eq. 9.

$$d = \left(\frac{q_{\propto(i;DFE)}\frac{\sqrt{MSE}}{r}}{\bar{Y}}\right) x\,100 \quad (9)$$

On what qa(i; DFE) is the critical value of Tukey's test at the level α of the probability of error (α=0,05 adopted this study), i is the number of simulated treatments (2 to 20 treatments), DFE is the number of degrees of freedom of error for the randomized block design, that is, (i-1).(r-1), MSE is the mean square of the error and, $\bar{Y}$ is the experimental mean. Therefore, when substituting the formula for the experimental variation coefficient expressed as a percentage, in the formula for calculating d, and isolating r, we have Eq. 10:

$$r = \left(\frac{q_{\propto(i;DFE)}\,CV}{d}\right)^2 \quad (10)$$

In this study, CV is expressed as a percentage and corresponds to the CV_{X0}, because this CV is expected for the experiment with the plot size (X_0) previously calculated. Using the largest coefficient of variation of plot size (CV_{X0}), the number of repetitions (r) was determined by an iterative process until convergence, for experiments in a randomized block design, in scenarios formed by combinations of i treatments (I = 2, 4, 6, ..., 20) and d (d = 5%, 10%, 15%, ..., 50%). For each cultivar, the highest estimate of plot size between crop rows was used. All analyzes were performed in the R software (R CORE TEAM, 2023) and the application Office Excel®.

RESULTS

Experimental variability

The results of the Levene test revealed that the variances are heterogeneous, as it was possible to observe the *p-value* lower than 0.05 in some beds, thus indicating that they are heterogeneous. When evaluating the heterogeneity of variances between rows of cultivation, within each cultivar, it was identified that in 2019 there was heterogeneity between rows of the beds of 17, 9, and 12% for cultivars 1, 2, and 3, respectively. In the year 2021, heterogeneity of 9, 6, and 6% was observed for cultivars 1, 2, and 3, respectively (Table 1).

Plot size

Plot size estimates ranged from three to twelve plants with a coefficient of variation (CV) in plot size from 8 to 26%, respectively, in the year 2019.

Table 1- Levene's test P-value between the rows of each bed, for the variables, shoot height (SH), root length (RL), shoot fresh mass (SFM), root fresh mass (RFM), and root diameter (RD) in the years 2019 and 2021.

Year	Cultivar	Bed	SH	RL	SFM	RFM	RD
2019	1	1	0.114	0.001*	0.962	0.542	0.116
		2	0.321	0.633	0.767	0.551	0.829
		3	0.056	0.019*	0.497	0.353	0.783
		4	0.023*	0.699	0.348	0.934	0.317
		5	0.595	0.698	0.309	0.493	0.468
		6	0.625	0.662	0.001*	0.007*	0.259
		7	0.136	0.043	0.164	0.263	0.767
	2	1	0.677	0.267	0.762	0.353	0.266
		2	0.126	0.442	0.958	0.929	0.890
		3	0.476	0.458	0.964	0.933	0.854
		4	0.356	0.288	0.045*	0.520	0.792
		5	0.256	0.717	0.093	0.055	0.251
		6	0.466	0.951	0.084	0.014*	0.056
		7	0.254	0.321	0.628	0.294	0.021*
	3	1	0.250	0.539	0.034*	0.005*	0.003*
		2	0.488	0.067	0.230	0.246	0.438
		3	1.000	0.075	0.953	0.524	0.779
		4	0.937	0.316	0.792	0.060	0.362
		5	0.452	0.391	0.051	0.003*	0.273
		6	0.782	0.376	0.582	0.795	0.697
		7	0.059	0.325	0.104	0.306	0.685
2021	1	1	0.360	0.757	0.057	0.093	0.136
		2	0.762	0.362	0.578	0.611	0.841
		3	0.028*	0.713	0.384	0.751	0.320
		4	0.981	0.342	0.718	0.159	0.764
		5	0.888	0.203	0.701	0.303	0.560
		6	0.886	0.030*	0.320	0.414	0.908
	2	1	0.060	0.445	0.996	0.837	0.491
		2	0.016*	0.264	0.041*	0.509	0.237
		3	0.751	0.702	0.592	0.989	0.254
		4	0.528	0.154	0.088	0.117	0.332
		5	0.530	0.314	0.531	0.662	0.829
		6	0.945	0.525	0.485	0.881	0.790
	3	1	0.824	0.522	0.122	0.278	0.664
		2	0.594	0.534	0.763	0.597	0.033*
		3	0.196	0.032*	0.167	0.895	0.505
		4	0.803	0.813	0.409	0.057	0.277
		5	0.228	0.589	0.052	0.858	0.646
		6	0.708	0.245	0.223	0.727	0.522

*P-value ≤ 0.05, indicates significance by F-test.

In the year 2021, the plot size ranged from three to nine plants with CV in plot size from 7 to 21% for cultivars 1, 2, and 3, respectively (Table 2).

The largest plot sizes observed in the year 2019 in each variable were five, seven, nine, eleven, and twelve plants with CV in the plot size of 10, 16, 19, 23, and 26% for the variables SH, RD, RL, RFM, and SFM, respectively. In the year 2021, the largest plot sizes for the variables SH, RD, RL, RFM, and SFM were six, six, five, nine, and nine plants, with a coefficient of variation of 13, 13, 11, 20, and 20%, respectively. As a single plot size recommendation for all variables, it is recommended that the largest plot size observed in this study be used (X_0 = twelve plants in the direction of the crop row with CV = 26%), which will be able to cover all the experimental variability of the other variables (Table 2).

Table 2 - Plot size (X_0, in plants) and coefficient of variation in plot size between parentheses (CV_{X0}, in %) of each row in each bed, for the variables, shoot height (SH), root length (RL), shoot fresh mass (SFM), root fresh mass (RFM) and root diameter (RD) in the years 2019 and 2021.

Year	Cultivar	Variable	Bed						
			1	2	3	4	5	6	7
2019	1	SH	4 (8)	5 (11)	5 (12)	3 (6)	3 (7)	3 (7)	4 (10)
		RL	5 (11)	5 (12)	6 (12)	5 (10)	5 (11)	5 (12)	6 (12)
		SFM	9 (19)	11 (26)	11 (25)	9 (21)	12 (26)	12 (26)	10 (22)
		RFM	8 (18)	8 (17)	10 (21)	10 (21)	9 (21)	10 (22)	11 (23)
		RD	6 (13)	5 (11)	6 (13)	6 (13)	6 (12)	6 (14)	5 (12)
	2	SH	3 (7)	4 (10)	5 (11)	5 (9)	3 (7)	4 (8)	4 (8)
		RL	5 (12)	6 (13)	6 (13)	9 (19)	4 (10)	9 (19)	6 (13)
		SFM	10 (21)	8 (18)	10 (22)	11 (24)	9 (20)	9 (19)	8 (18)
		RFM	9 (19)	10 (19)	8 (18)	10 (21)	11 (23)	8 (17)	10 (21)
		RD	6 (13)	5 (12)	5 (11)	6 (13)	6 (14)	6 (13)	7 (16)
	3	SH	5 (11)	3 (7)	4 (7)	4 (8)	5 (10)	4 (7)	5 (10)
		RL	4 (9)	4 (9)	5 (11)	4 (9)	5 (10)	6 (12)	5 (11)
		SFM	9 (20)	7 (16)	7 (16)	7 (16)	8 (17)	9 (19)	8 (18)
		RFM	8 (19)	7 (16)	7 (16)	7 (16)	9 (21)	9 (19)	9 (20)
		RD	5 (12)	5 (11)	3 (8)	4 (9)	6 (13)	6 (13)	5 (11)
2021	1	SH	6 (13)	4 (9)	4 (8)	4 (8)	4 (8)	3 (7)	-
		RL	4 (8)	5 (11)	5 (11)	5 (10)	4 (9)	5 (11)	-
		SFM	8 (17)	7 (18)	9 (19)	7 (16)	9 (20)	8 (18)	-
		RFM	8 (17)	8 (17)	7 (16)	8 (17)	9 (20)	8 (17)	-
		RD	5 (11)	4 (9)	4 (9)	4 (9)	5 (11)	4 (9)	-
	2	SH	3 (7)	4 (9)	4 (9)	3 (7)	3 (7)	4 (8)	-
		RL	4 (9)	4 (9)	5 (10)	5 (10)	4 (9)	4 (9)	-
		SFM	8 (18)	9 (20)	9 (20)	8 (17)	7 (16)	9 (20)	-
		RFM	8 (18)	8 (17)	8 (17)	8 (17)	8 (18)	8 (17)	-
		RD	4 (10)	5 (10)	4 (10)	6 (13)	5 (10)	5 (11)	-
	3	SH	3 (7)	3 (7)	4 (8)	3 (7)	3 (6)	3 (7)	-
		RL	4 (9)	4 (8)	4 (9)	4 (10)	4 (9)	4 (10)	-
		SFM	8 (18)	8 (17)	8 (18)	8 (17)	9 (19)	8 (17)	-
		RFM	8 (17)	8 (17)	6 (14)	8 (17)	7 (15)	8 (17)	-
		RD	5 (10)	5 (11)	4 (9)	4 (10)	4 (9)	4 (9)	-

Sample Size

The results of sample sizes (in number of plants) varied according to the analyzed variable, cultivar, year, and the minimum differences considered between means (D%). For both years and cultivars, it was observed that the largest sample sizes always prevail in the variables fresh mass of shoots and fresh mass of roots. For a semi-amplitude of the 95% confidence interval (D%) equal to 5% of the mean, the largest sample size observed for the variables SH, RL, SFM, RFM, and RD in the year 2019 were six, nine, twelve, eleven and seven plants, respectively. As for the year 2021, the largest sample size observed for the variables SH, RL, SFM, RFM, and RD were six, five, nine, nine, and five plants respectively (Table 3).

For a semi-amplitude of the 80% confidence interval (D%) equal to 20% of the mean, the largest sample size observed for the variables SH, RL, SFM, RFM, and RD in the year 2019 were three, seven, eleven, nine and five plants, respectively. As for the year 2021, the largest sample sizes observed for the variables SH, RL, SFM, RFM, and RD were four, three, seven, seven, and three plants, respectively (Table 3). If the researcher chooses to use D = 20%, it will result in a reduction of 32, 22, 9, 18, and 29% in the number of plants needed to be sampled in the plot to evaluate the variables SH, RL, SFM, RFM, and RD, respectively.

Number of repetitions

The number of repetitions for each variable was determined from the largest plot size of each

Table 3 - Sample size in the plot (number of plants) and minimum differences between means (D= 5, 10, 15, and 20%), for each row in each bed and cultivar (Cult.) for the variables height of shoot (SH), length of root (RL), shoot fresh mass (SFM), root fresh mass (RFM) and root diameter (RD) in the years 2019 and 2021.

Year	Cult.	Bed	SH				RL				SFM				RFM				RD			
			5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20
2019	1	1	4	3	2	2	5	4	3	3	9	8	8	7	8	8	7	6	6	5	5	4
		2	5	4	4	3	5	5	4	4	11	11	11	10	8	7	7	6	5	4	3	3
		3	5	5	4	3	5	5	4	4	11	11	10	10	9	9	9	8	5	5	4	4
		4	2	2	1	1	4	4	3	3	9	9	8	8	9	9	9	8	6	5	4	4
		5	3	3	2	2	5	4	4	3	12	12	11	11	9	9	8	7	5	5	4	4
		6	3	2	2	1	5	5	4	4	12	12	11	11	10	9	9	8	6	6	5	4
		7	4	3	3	3	5	5	4	4	10	10	9	8	11	10	10	9	5	5	4	4
	2	1	3	2	2	1	5	5	4	3	9	9	9	8	8	8	7	7	6	5	4	4
		2	4	4	3	3	6	5	5	4	8	8	7	6	8	8	7	7	5	5	4	4
		3	5	4	4	3	5	5	4	4	10	10	9	9	8	8	7	6	5	4	4	3
		4	4	3	3	2	9	8	8	7	11	10	10	9	9	9	9	8	6	5	5	4
		5	3	2	2	1	4	4	3	3	9	9	8	8	11	10	10	9	6	6	5	5
		6	3	3	2	1	4	3	2	2	9	8	8	7	8	7	7	6	6	5	4	4
		7	3	3	2	2	5	5	4	4	8	7	7	6	10	9	9	8	7	7	6	5
	3	1	5	4	4	3	4	3	3	2	9	8	8	7	8	8	7	7	5	5	4	4
		2	3	3	2	1	4	3	3	2	7	7	6	5	7	6	6	5	5	4	4	3
		3	3	2	2	1	5	4	4	3	7	7	6	5	7	6	6	5	3	3	2	1
		4	3	3	2	2	4	3	3	2	7	6	6	5	7	6	6	5	4	3	3	2
		5	4	4	3	3	4	4	3	3	7	7	6	5	9	9	8	8	6	5	5	4
		6	3	3	2	1	5	5	4	4	9	8	8	7	8	8	8	7	5	5	4	4
		7	4	4	3	3	5	4	4	3	8	8	7	7	9	9	8	7	5	4	4	3
2021	1	1	6	5	5	4	4	3	3	2	8	7	7	6	8	7	7	6	5	4	3	3
		2	4	3	3	2	5	4	4	3	7	6	6	5	8	7	6	6	4	4	3	3
		3	3	3	2	2	4	4	3	3	9	8	8	7	7	7	6	6	4	4	3	3
		4	4	3	3	2	4	4	3	3	7	7	6	6	8	7	7	6	4	3	3	2
		5	4	3	3	2	4	4	3	3	9	9	8	7	9	8	8	7	5	4	3	3
		6	3	2	2	1	5	4	3	3	7	7	6	6	7	7	6	6	4	3	3	2
	2	1	3	3	2	1	4	3	2	2	8	8	7	6	8	8	7	6	4	4	3	3
		2	4	3	3	2	4	3	3	2	9	8	8	7	8	7	7	6	4	4	3	3
		3	4	4	3	3	4	4	3	3	9	8	8	7	7	7	6	6	4	4	3	3
		4	3	2	2	1	4	4	3	3	8	7	7	6	7	7	6	6	5	5	4	4
		5	3	2	2	1	4	3	3	2	7	6	6	5	8	8	7	6	5	5	4	4
		6	3	3	2	2	4	3	3	2	9	8	8	7	8	8	7	7	5	4	4	3
	3	1	3	2	2	1	4	3	3	2	8	7	7	6	8	7	7	6	4	4	3	3
		2	3	2	2	1	4	4	3	3	8	7	7	6	7	7	6	6	5	4	3	3
		3	3	3	2	2	4	3	3	2	8	8	7	6	6	6	5	5	4	3	3	2
		4	3	2	2	1	4	4	3	2	7	7	6	6	8	7	6	6	4	4	3	3
		5	3	2	2	1	4	3	3	2	9	8	8	7	7	6	5	5	4	3	3	2
		6	3	2	2	1	4	4	3	3	8	7	7	6	8	7	7	6	4	3	3	3

variable, observed in both years and trials, with their respective coefficients of variation. For the variables SH, RL, SFM, RFM, and RD, the number of repetitions ranged from three, five, eight, eight, and four repetitions, from the combination of 2 treatments with d = 50%, to 251, 536, 1003, 785 and 380 repetitions (2 treatments with d = 5%), respectively. All scenarios are formed by combinations of i treatments (I = 2, 4, 6, ..., 20) and d minimum differences between means of treatments (d = 5 %, 10 %, 15 %, ..., 50 %), to be detected as significant at 5% probability, by Tukey's test (Table 4 and, Table 5).

From the plot size (X_0) the researcher can establish the relationship between i (treatments), d (differences between means of treatments), and number of repetitions. For example, when considering plots of six, nine, twelve, eleven, and seven plants in an experiment with two treatments (i = 2), three, five, eight, eight, and four repetitions are necessary, respectively, so that the minimum difference of 50 % is considered significant by Tukey's test, for the variables SH, RL, SFM, RFM, and RD, respectively. Thus, as a single recommendation of the number of repetitions for any variable evaluated in this study, for experiments with the carrot crop, and with a minimum significant difference from the Tukey test expressed as a percentage of the mean of 50%, plots of 12 plants should be adopted, with eight replicates (Table 4 and, Table 5).

DISCUSSION

Reduction of experimental variability

After the previous test of the homogeneity of the variances, it was verified that some rows of the uniformity test are heterogeneous. Experimental variability in vegetables may be due to several factors, such as intensive management, high demand for labor, heterogeneity in soil fertility, occurrence of pests, diseases, and weeds (LÚCIO & BENZ, 2017).

Due to these and other factors, it is recommended that in future experiments with the carrot crop, the researchers use a randomized block design, following the recommendation of (LÚCIO & SARI, 2017) where each block/repetition will consist of a crop row. This procedure avoids inflating the estimate of the experimental error and, consequently, increases the experimental precision. This recommendation was also made, for example, by KRYSCZUN et al. 2018, (TARTAGLIA et al., 2021) and, (LAMBRECHT et al., 2022) for other vegetable crops.

Plot size

The plot size is mainly influenced by the variability of the experimental area, and the main ways to minimize the effects of this variability are

Table 4 - Number of repetitions for experiments in randomized block design, in scenarios formed by combinations of i treatments (I = 2, 3, 4, ..., 20) and d minimum differences between means of treatments to be detected as significant at 5% probability, by Tukey's test, expressed as a percentage of the mean of the experiment (d= 5, 10, 15, ..., 50%), for the variables SH, RL and, SFM from the highest observed plot size for each variable (X_0 = 6, 9 and, 12 plants) and coefficient of variation in plot size (CV_{X0} = 13, 19 and, 26%, respectively).

Variable	----i----	-------------------------------Semi-amplitude of the mean confidence interval (d%)-------------------------------									
		5	10	15	20	25	30	35	40	45	50
SH[1]	2	251	63	28	16	10	7	5	4	3	3
	4	162	41	18	10	6	5	3	3	2	2
	6	163	41	18	10	7	5	3	3	2	2
	8	168	42	19	11	7	5	3	3	2	2
	10	174	43	19	11	7	5	4	3	2	2
	12	183	46	20	11	7	5	4	3	2	2
	14	186	47	21	12	7	5	4	3	2	2
	16	188	47	21	12	8	5	4	3	2	2
	18	196	49	22	12	8	5	4	3	2	2
	20	203	51	23	13	8	6	4	3	3	2
RL	2	536	134	60	33	21	15	11	8	7	5
	4	347	87	39	22	14	10	7	5	4	3
	6	348	87	39	22	14	10	7	5	4	3
	8	360	90	40	22	14	10	7	6	4	4
	10	371	93	41	23	15	10	8	6	5	4
	12	390	98	43	24	16	11	8	6	5	4
	14	398	100	44	25	16	11	8	6	5	4
	16	401	100	45	25	16	11	8	6	5	4
	18	418	104	46	26	17	12	9	7	5	4
	20	434	108	48	27	17	12	9	7	5	4
SFM	2	1003	251	111	63	40	28	20	14	10	8
	4	649	162	72	41	26	18	13	10	8	6
	6	652	163	72	41	26	18	13	10	8	7
	8	673	168	75	42	27	19	14	11	8	7
	10	695	174	77	43	28	19	14	11	9	7
	12	731	183	81	46	29	20	15	11	9	7
	14	745	186	83	47	30	21	15	12	9	7
	16	751	188	83	47	30	21	15	12	9	8
	18	783	196	87	49	31	22	16	12	10	8
	20	812	203	90	51	32	23	17	13	10	8

[1]SH - shoot height, RL - root length and, SFM - shoot fresh mass.

Table 5 - Number of repetitions for experiments in randomized block design, in scenarios formed by combinations of i treatments (I = 2, 3, 4, ..., 20) and d minimum differences between means of treatments to be detected as significant at 5% probability, by Tukey's test, expressed as a percentage of the mean of the experiment (d= 5, 10, 15, ..., 50%), for the variables RFM, RD from the highest observed plot size for each variable (X_0 = 11 and, 7 plants) and coefficient of variation in plot size (CV_{X0}= 23 and, 16%, respectively).

Variable	----i----	----------------------------------Half-amplitude of the mean confidence interval (d%)----------------------------------									
		5	10	15	20	25	30	35	40	45	50
RFM[1]	2	785	196	87	49	31	22	16	12	10	8
	4	508	127	56	32	20	14	10	8	6	5
	6	510	128	57	32	20	14	10	8	6	5
	8	527	132	59	33	21	15	11	8	7	5
	10	544	136	60	34	22	15	11	8	7	5
	12	572	143	64	36	23	16	12	9	7	6
	14	583	146	65	36	23	16	12	9	7	6
	16	588	147	65	37	24	16	12	9	7	6
	18	612	153	68	38	24	17	12	10	8	6
	20	635	159	71	40	25	18	13	10	8	6
RD	2	380	95	42	24	15	11	8	6	5	4
	4	246	61	27	15	10	7	5	4	3	2
	6	247	62	27	15	10	7	5	4	3	2
	8	255	64	28	16	10	7	5	4	3	3
	10	263	66	29	16	11	7	5	4	3	3
	12	277	69	31	17	11	8	6	4	3	3
	14	282	71	31	18	11	8	6	4	3	3
	16	284	71	32	18	11	8	6	4	4	3
	18	296	74	33	19	12	8	6	5	4	3
	20	308	77	34	19	12	9	6	5	4	3

[1]RFM - root fresh mass, and RD - root diameter.

its correct dimensioning and the use of an adequate experimental design (STORCK, 2006). In the case of future experiments to be carried out with the carrot crop, it is recommended that the researcher use the largest plot size indicated in this work for each variable to be analyzed (six, seven, nine, eleven, and twelve plants for the variables SH, RD, RL, SFM, and RFM, respectively). As a single plot size recommendation for all variables, it is indicated that the largest plot size of this work (twelve plants) be used, since using the largest plot size, it is possible to cover all the variability of the other rows and variables, in order to have a good reliability of the results, with the certainty that the data reflect the real effects of the tested treatments (LAMBRECHT et al., 2022).

Results very similar to those observed in this study, referring to plot size, were recorded for the carrot crop by the researchers (VIEIRA & SILVA, 2008) in a study on the minimum plot size for evaluating root traits in carrots whose experiment was carried out in 2004 in three cultivation sites in the city of Brasília – Distrito Federal, São Gotardo – Minas Gerais, and Lapão – Bahia, in which the authors observed that thirteen plants per plot are sufficient to ensure adequate evaluation. This study showed us that even after seventeen years of cultivation, another cultivation site, and cultivars under study, the plot size practically remains the same, indicating low experimental variability in space and time.

Sample size

For the carrot crop, it is recommended that four, five, seven, nine, and eleven plants be sampled per plot, in the direction of the crop row for the variables SH, RD, RL, RFM, and SFM, respectively, with a semi-amplitude of confidence interval (D%) equal to 20% of the mean. With this recommendation, 50, 71, 77, 81 and 91% of the plants in each row of cultivation will be sampled for the variables SH, RD, RL, RFM, and SFM, respectively, that is, there will be a reduction in the evaluation time, labor and financial resources.

As a recommendation for a single sample size for the carrot crop, it is recommended to use the largest sample size found in this study, which is eleven plants, with D = 20%. In this sense, several researches have already been carried out with other vegetable crops, such as the tomato crop (LÚCIO et al., 2012), eggplant (KRYSCZUN et al., 2018), pea (TARTAGLIA et al., 2021) and, onion (LAMBRECHT et al., 2022), being similar values of a sample size to those observed in this work were found.

Adequate sampling is extremely important, as the researcher will be able to carry out a greater number of evaluations in the same period of time, maximizing his research (LAMBRECHT et al., 2023). The use of sampling in the plots causes an additional source of experimental variation, which is defined as sampling error, and the greater the variation of the data in relation to the mean, the greater the number of plants needed to compose the sample due to the experimental error (SILVA et al., 2019). In this way, the increase in the number of sampled plants promotes a reduction in the sampling error and increases the reliability and precision of the results (CARGNELUTTI FILHO et al., 2018).

Number of repetitions

Based on the plot size (X_0) the researcher can establish the relationship between i (treatments), d (differences between means of treatments), and number of repetitions. For example, considering plots of twelve carrot plants, for the SFM variable, in an experiment with a number of treatments ranging from two to twenty (i = 2 and 20), eight repetitions are necessary for the minimum difference of 50% to be considered significant by Tukey's test. Thus, it can be recommended for experiments with the carrot crop, with a minimum significant difference from the Tukey test expressed as a percentage of the mean of 50%, to adopt plots of twelve plants per crop row, with eight replicates (Table 4).

It is worth noting that the smaller the significant differences that the researcher intends to detect between the treatments, the smaller the number of repetitions required. For example, for the SFM variable, if the researcher chooses to evaluate three treatments (i = 3) and his objective is to find minimum significant differences between treatments of 25%, he must plan the experiment with at least 26 repetitions (Table 4). But, this high number of repetitions may be unfeasible from an economic point of view, in addition to the need for high availability of labor and experimental area, therefore, when planning the experiment, the researcher must consider the combination of minimal significant differences between treatments to be detected, the size of the experimental area, the availability of manpower, the financial resources and the number of treatments to be evaluated (LÚCIO et al., 2020).

When it is intended to prove statistically small minimum significant differences between treatments, it is advantageous to work with smaller plot sizes, with a greater number of repetitions (HENRIQUES NETO et al., 2004; SOUSA et al., 2015). In addition, this condition allows to reduce the experimental error, increase the experimental precision, and increase the reliability of the research results (ROSSETTI, 2002).

It is important to remember that in the face of this study, the researcher has the possibility to identify which is the size of the plot, sample, and the number of repetitions that best fits his situation, taking into account the variables to be analyzed, availability of experimental area, human and financial resources, as well as the number of treatments to be analyzed and the minimum significant differences between the treatments that you want to find in the experiment to meet your objectives.

CONCLUSION

For the carrot crop, the plot size to evaluate the variables shoot height, root length, shoot fresh mass, root fresh mass, and root diameter, is six, nine, twelve, eleven, and seven plants in the row sense, respectively.

The sample size to evaluate the variables shoot height, root length, shoot fresh mass, root fresh mass, and root diameter, is four, seven, eleven, nine, and five plants, respectively, in the direction of row considering a semi-amplitude of the confidence interval (D%) equal to 20% of the mean.

For the variables shoot height, root length, shoot fresh mass, root fresh mass, and root diameter, three, five, eight, eight, and four replicates are required, respectively, to evaluate up to 20 treatments in the experimental design randomized blocks so that minimum significant differences of 50% between means are detected.

As a single recommendation for plot size, sample, and several replicates, plots of twelve plants are recommended, samples of eleven plants in the direction of the row, with eight replicates.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the study reported in this paper.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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