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CIÊNCIAS AGRÁRIAS

Correlações canônicas para rabanete (*Raphanus sativus* l.) e as variáveis de crescimento

Canonical correlations for radish (Raphanus sativus l.) growth variables

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RESUMO

O rabanete apresenta poucos estudos que envolvem atributos de crescimento e suas relações, que são de grande importância para avaliar o rendimento final da cultura. O objetivo deste trabalho foi estimar as relações lineares entre variáveis de crescimento, avaliar grupos de variáveis da parte aérea e radicular por meio da análise de correlações canônicas e da distância genética entre três cultivares de rabanete. O delineamento experimental foi em blocos casualizados, organizado em esquema fatorial: três (cultivares de rabanete) x sete (épocas de coleta das plantas 13, 16, 19, 22, 25, 28 e 31 dias após a semeadura), dispostos em quatro repetições. As plantas foram coletadas em intervalos regulares de três dias, iniciando-se no décimo terceiro dia após a semeadura até o final do ciclo vegetativo. As variáveis analisadas em cada coleta foram: número de folhas, área foliar, diâmetro transversal e longitudinal, comprimento da raiz, parte aérea, raiz e matéria seca total. Os dados obtidos foram submetidos a uma análise conjunta, e as variáveis medidas foram submetidas à correlação linear com a significância baseada no teste t a 1 e 5% de probabilidade, esta análise teve o intuito de evidenciar a tendência de associação linear para as variáveis e análise de correlações canônicas. Plantas de rabanete com maior área foliar apresentam menor desenvolvimento radicular, com base no coeficiente de correlação canônica. Houve correlações positivas entre todas as variáveis analisadas, com destaque para área foliar com matéria seca, altura de planta e número de folhas.

Palavras-chave: Análise multivariada; correlação de Pearson; atributos morfológicos.

ABSTRACT

Radish has few studies involving growth attributes and their relationships, which are of great importance to evaluate the final yield of the crop. The objective of this study was to estimate the linear relationships between growth variables, evaluate groups of variables of the aerial part and root through the analysis of canonical correlations and the genetic distance between the three radish cultivars. The experimental design was in randomized blocks, organized in a factorial scheme: three (radish cultivars) x seven (plant collection times 13, 16, 19, 22, 25, 28 and 31 days after sowing), arranged in four replicates. The plants were collected at regular intervals of three days, starting on the thirteenth day after sowing until the end of the vegetative cycle. The variables analyzed in each collection were: number of leaves, leaf area, transverse and longitudinal diameter, root length, aerial part, root and total dry matter. The data obtained were subjected to a joint analysis, and the measured variables were subjected to linear correlation with significance based on the t-test at 1 and 5% probability. This analysis aimed to demonstrate the tendency of linear association for the variables and analysis of canonical correlations. Radish plants with larger leaf area present lower root development, based on the canonical correlation coefficient. There were positive correlations between all variables analyzed, with emphasis on leaf area with dry matter, plant height and number of leaves.

Keywords*: Multivariate analysis; Pearson correlation; morphological attributes.*

1. INTRODUCTION

Radish (*Raphanus sativus* L.) is a species of Brassicaceae family, nutritionally rich in vitamins, with high amounts of dietary fibers, antioxidant activity and isothiocyanates (Camargo *et al*., 2020). This species can be used as intercalary culture among others with a longer cycle (Damasceno *et al*., 2019). Due to its short cycle and rusticity (Filgueira, 2021), it provides a fast profitability for the family producers. However, the culture is influenced by poorly managed management practices.

Different factors can influence the adequate establishment of the plants stand on the field, the quality of the roots and the final productivity of the crop. These include inadequate cultural practices, water stress and nutritional stress (Bregonci *et al*., 2021), as well as soil physical conditions (Silva *et al*., 2022). The knowledge about the factors related to the growth of the plants allows to plan the

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cultivation, being the association among these factors an important tool in the study of the plant because they influence in the final production. A great number of studies with radish related to the production evaluation (Puliti *et al*., 2019), plant growth (Pereira *et al*., 2021) and fertilization (Oliveira *et al*., 2020; Maia *et al*., 2021) are found in the bibliography. However, no records of growth ratios with dry matter in radish were found.

The study of the relation through the correlation among the morphological variables of the plant allows to infer indirectly about the productive potential (Oliveira *et al*., 2022), as well as it also allows to evaluate the effect of the fertilization and the result of different techniques of cultural management (Martuscello *et al*., 2022).

The correlation among groups of characters measured in plants allows us to determine which of these attributes are most important in obtaining a product with a higher standard (Brum *et al*., 2021). Biometric analyzes, through canonical correlations, allow gains higher than those obtained with simultaneous selection, this process being because this is not restricted to the evaluation of only two characteristics, allowing, in contrast, the verification of a set of attributes (Bezerra *et al*., 2021). In addition, this type of analysis makes it possible to compare agronomic and physiological attributes (Bezerra *et al*., 2021).

The canonical correlation represents a multivariate statistical model that enables the determination of the linear relations that occur between two orders or groups of variables (X and Y) (Protásio *et al*., 2012). The basic principle of this type of analysis is the development of a linear combination in each of the sets of variables, making it possible to maximize the correlation among the intergroup attributes (Nascimento Filho et *al*., 2022).

This analysis considers the importance of simplifying the understanding and the relationship among a set of variables. In canonical correlation we consider the interrelation of groups of variables, being this technique very used in the accomplishment of exploratory studies (Nascimento Filho *et al*., 2022). The objective of this work was to estimate the linear relationships among the growth variables, to evaluate the groups of shoot and root variables by the analysis of canonical correlations for three radish cultivars.

2. DEVELOPMENT

2.1 Conditions, experimental design, and cultivars used

The experiment was carried out at Federal University of Pelotas, Municipality of Capão do Leão, Rio Grande do Sul (31º 52 'S, 52º 21' W, 13 m altitude), in an arch type of greenhouse, arranged in the north-south direction, cased with low density polyethylene film. The climate of the region is temperate with well distributed rains and hot summer, being of type Cfa by the classification of Köppen.

The cultivars used were: Cometo®, Crimson Vip® and Vermelho Redondo®. The sowing was carried out in polyethylene vessels with a capacity of ten liters, using Salic Eutric Haplic Planosol soil type as substrate. The plant spacing used was 0.20 x 0.08 m (Filgueira, 2021), and soil correction was performed according to previous analysis and based on the Manual of Fertilization and Liming (CQFS RS/SC, 2016). Irrigation was with a hand watering can, keeping the humidity close to the field capacity. The experimental design was a randomized block design, organized in a factorial scheme:

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three (radish cultivars) x seven (collection moments of 13, 16, 19, 22, 25, 28 and 31 days after sowing), arranged in four replicates.

2.2 Variables analyzed

To obtain the primary growth and dry matter data, the plants were collected from the thirteenth day after sowing, at regular intervals of three days, until the end of the crop cycle. In each collection, four plants of each cultivar were cut close to the soil, separated into organs (shoot and root) and directed to the oven with forced ventilation at a temperature of 70 ± 2°C, for 72 h, and then being determined shoot (W_{AP}) and root (W_R) dry matter, with the aid of a precision scale. The leaf area (A_l) was determined with Li Cor brand measurer, model LI-3100. The height of the plants (H) was measured from the soil level to the upper end of the longer leaf, using a tape measure. Root length (L_r) was determined at the insertion of the leaves to the end of the root, using a tape measure. The number of leaves (N_l) was obtained by direct counting. The transversal (D_t) and longitudinal (D_l) diameter of the root were determined with the aid of a digital caliper, being expressed in mm.

2.3 Statistical analysis

The data were submitted to analysis of variance at 1 and 5% of probability, to verify the assumptions, Shapiro-Wilk normality test (1965), and Hartley’s homogeneity of variances test were carried out (Ramalho *et al.*, 2012). The data were analyzed together, and the measured variables were subjected to Pearson's linear correlation with significance based on the t-test at 1 and 5% probability. This analysis aimed to show the trend of linear association for the variables (Steel *et al.*, 1997). Then, the matrix of linear associations was subjected to the multicollinearity diagnosis through the number and conditions (NC) of the matrix (Cruz and Carneiro, 2003), in this way, the variable Wt was removed to minimize line and column dependencies of the matrix of correlation, it was again tested and low colinearity was obtained without serious problems in the matrix. It was subdivided into aerial part variables (group I): NF, A, AF and WPA, and root variables (group II): DT, D1, CR and WR. The canonical correlation analysis was performed, where the significance among groups of variables was obtained by the chi-square test (Cruz and Regazzi, 1997).

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3. RESULTS AND DISCUSSIONS

There was a significant interaction among the variation factors tested at 1% of probability for leaf area, root length, longitudinal diameter, and total dry matter, in contrast, the number of leaves showed a significant interaction with 5% of probability. Significant effect occurred to cultivate at 1% and probability for leaf area, longitudinal diameter, and total dry matter. For the collection moments factor, a significant effect was observed for none of the analyzed variables.

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The coefficient of variation (CV) for leaf number, leaf area, plant height, root length, longitudinal diameter, transverse diameter, shoot, root, and total dry matter showed a range from 13.8 to 24.6 % (Table 1). Significant interaction was observed for the number of leaves, leaf area, root length, total diameter, and total dry matter, indicating that these variables are responsive to the effects of cultivars and collection moments (Table 1).

Table 1 - Summary of the variance analysis of three cultivars (Cult) of radish in seven moments (Temp) of collection.

SV	DF	N_l	A_l	H	L_r
		MeanSquares			
Blocks	3	0.32	395.7	2.26	0.91
Cultivars	2	1.02^{ns}	2849.7**	3.39^{ns}	11.2^{ns}
Times	6	68.9^{ns}	111559.1^{ns}	350.1^{ns}	104.9^{ns}
Cult *x* Temp	12	1.23*	1466.6**	4.47^{ns}	9.1**
Residue	60	0.44	577.3	2.86	3.89
Average		4.78	102.5	10.5	13.3
CV (%)		13.8	23.4	16.1	14.7

SV	DF	D_l	D_t	W_{AP}	W_R	W_t
		MeanSquares				
Blocks	3	50.8	16.5	0.01	0.01	0.01
Cultivars	2	69.9**	26.8^{ns}	0.02^{ns}	0.22^{ns}	0.12**
Times	6	1917.1^{ns}	2137.5^{ns}	2.01^{ns}	3.58^{ns}	10.8^{ns}
Cult *x* Temp	12	35.7**	15.4^{ns}	0.09^{ns}	0.07^{ns}	0.11**
Residue	60	26.1	6.12	0.01	0.01	0.02
Average		23.8	14.8	0.42	0.48	0.90
CV (%)		21.4	16.6	24.6	15.7	16.8

(Number of leaves (N_l), plant height (H), leaf area (A_l), transverse diameter (D_t) and longitudinal diameter (D_l), root length (L_r), shoot (W_{AP}), root (W_R) and total dry matter (W_t). ** Significant at 1% of probability level. * Significant at 5% of probability level. ^{ns} Not significant.

SOURCE: TIAGO PEDÓ

3.1 Pearson's linear correlation

Pearson's linear correlation analysis performed for the eight variables revealed significance at 1 and 5% by the t test for all variables. The degree of association among growth variables over time indicates an accentuated correlation perspective (Table 2). The results of the correlation analysis showed a positive correlation among the number of leaves, plant height, leaf area, transverse and longitudinal diameter, root length, shoot, root, and total dry matter.

Table 2 - Pearson correlation coefficients analyzed in seven moments of radish collection.

Variables	H	A_l	D_t	D_l	L_r	W_{AP}	W_R	W_t
N_l	0.98**	0.95**	0.96**	0.92**	0.90**	0.87**	0.89**	0.91**
H		0.93**	0.95**	0.90**	0.90**	0.87**	0.85**	0.88**
A_l			0.98**	0.96**	0.85**	0.97**	0.93**	0.98**
D_t				0.95**	0.83**	0.91**	0.94**	0.95**
D_l					0.79**	0.92**	0.95**	0.96**
L_r						0.83**	0.78**	0.82**
W_{AP}							0.89**	0.96**
W_R								0.98**

(Number of leaves (N_l), plant height (H), leaf area (A_l), transversal (D_t) and longitudinal diameter (D_l), root length (L_r), shoot (W_{AP}), root (W_R) and total dry matter (W_t). **Significant at 1% of probability by t test).

SOURCE: TIAGO PEDÓ

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The results obtained for the number of leaves and the leaf area over time showed a correlation coefficient of r = 0.95, showing a strong linear association for the emission and leaf expansion, being an important factor to estimate the growth of the photosynthetic organ of the plants (Table 2). It was verified that the correlation coefficient corresponding to plant height and root length was r = 0.90, which is considered as a strong correlation (Figueiredo Filho, 2021; Silva Júnior, 2019). However, for transverse and longitudinal diameters, the correlation coefficient was r = 0.95 and characterizes these two attributes as important for estimating root growth of radish plants.

Different correlation coefficients were observed for dry matter variables (Table 2). When analyzing the dry matter of shoot and root, there was a correlation of r = 0.89, while for the aerial and total part the correlation was r = 0.96 being like the verified between the root and the total (r = 0.98). Significant correlations were observed between leaf area and total dry matter (r = 0.98), in contrast, with leaf number and total dry matter the correlation was r = 0.91.

Leaf area and leaf number evaluations are important attributes related to plant growth and development, since these characteristics are related to the amount of solar radiation intercepted and absorbed by the leaves, which demonstrates the energy conversion efficiency (Heinemann *et al.,* 2019). The morphological characteristics are influenced by several abiotic factors (Martuscello *et al*., 2022) and biotic, and can be used to evaluate the productive potential of radish genotypes.

The use of Pearson's linear correlation to evaluate the degree of association among growth variables over time was efficient for radish cultivars, as observed between leaf area and leaf number. Because efficient estimates were obtained due to the number of observations (N = 84) in this way, the linear trends among the variables for the radish culture are reliable and representative, having a repeatability character in later studies with the culture. For sugarcane, Oliveira *et al.* (2022) observed a correlation between number of leaves and leaf area, demonstrating that such attributes contribute to the biomass production of the plants of this species.

Between the leaf and dry matter variables, a positive and significant correlation was observed. According to Martuscello *et al.* (2022), there is a positive correlation between leaf elongation rate and shoot dry matter for the Maasai grass. In wheat, the leaf area index, and the efficiency of the use of solar radiation present positive and highly significant correlation with the production of dry matter by plants (Heinemann *et al*., 2019). The linear trends obtained by the correlation coefficients observed in this analysis can be used in later studies to estimate the growth of radish genotypes.

Due to the existence of a higher correlation among similar variables, these results indicate that increasing the length does not necessarily increase the total dry matter, based on the lower values of correlation between root length and height of the plants with the total dry matter (Table 2).

3.2 Canonical correlation

The analysis of canonical correlation performed in groups of pre-established variables indicates the significance of the three canonical pairs by the chi-square test, this shows dependence among the groups of variables measured. The intergroup correlation (Table 3) revealed for the first canonical pair a correlation of r = 1.09 that confer interdependence among the variables of both groups. In this way, radish plants with lower Dt and D1 (group II) were determinant for A_l and H reduction (group I). In this sense, it is evident the simultaneous growth for the aerial and root parts.

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Table 3 - Estimates of correlations and canonical pairs among aerial part variables (Group I) and root variables (Group II), in three radish cultivars.

VARIABLES	CANONICAL PAIRS		
	1st	2nd	3rd
		Group I	
N_l(1)	-0.3547	0.91997	0.05538
H	-0.38156	0.90167	0.2019
A_l	-0.40583	0.89735	-0.15965
W_{AP}	-0.29134	0.89322	-0.19551
		Group II	
D_t	-0.52202	0.84377	-0.10245
D_1	-0.38688	0.87133	-0.24637
L_r	-0.05561	0.96702	0.22272
W_R	-0.31621	0.86371	-0.37842
R	1.090	0.976	0.563
A	0.001	0.001	0.013

(1) Number of leaves (N_l), plant height (H), leaf area (A_l), transversal (D_t) and longitudinal (D_l) diameter, length of root (L_r), dry matter of shoot (W_{AP}) and of root (W_R).

SOURCE: TIAGO PEDÓ

Radish plants under these conditions prioritize the development of the photosynthetic structures, increase the number of leaves and the height of the plants, thus potentiate the production of photoassimilates, which are carried to the development of the roots transversally and longitudinally (Puliti *et al.*, 2019).

The third canonical pair showed a correlation of r = 0.56 which associates plants with lower W_r (Group I) being these determinants for greater A (Group I). However, for the radish crop it presents a short cycle and the part of commercial interest is the root, with that, the presence of association of the highest H and lowest W_r, or vice versa, can be justified by the plants initially show growth and development of the aerial part (leaves, petioles), and these morphological structures act as photosynthetic mechanisms in the production of photoassimilates that are later directed to the root structures.

In contrast, plants with higher shoot growing period (height) show a lower orientation of photoassimilates directed towards the root, which interferes directly with the dry matter of the root structure (Costa et al., 2019).

4. FINAL CONSIDERATIONS

The presence of significance among the canonical pairs indicates dependence among the groups of variables of the aerial and root parts. Radish plants with larger leaf area demonstrate lower root development, based on the coefficient of canonical correlation.

There were positive correlations among all the analyzed variables, especially the leaf area with dry matter (0.98 **), plant height (0.93 **) and leaf number (0.95 **), based on the Pearson correlation coefficient.

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