ADJUSTING THE OPTIMAL ARRANGEMENT OF PLANTS TO MAXIMIZE THE PRODUCTIVITY AND QUALITY OF LINSEED GRAINS

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ABSTRACT - Understanding and exploring the productive potential of crops guarantees the economic return and sustainability of the activity. In addition to genetic improvement and biotechnological events, crop management practices contribute to the expression of high crop performance. The aim of this work was to highlight the effects of row spacing and seed densities on the agronomic performance of flaxseed. The trial was developed in the experimental area of the Regional Institute of Rural Development, which belongs to the Regional University of the Northwest of the Brazilian State of Rio Grande do Sul. The experimental design was randomized blocks, and the treatments were structured in factorial scheme three (spacings) x six (densities) with three replications per treatment, totaling 54 experimental units. We used three spacings between rows, 18 cm, 36 cm and 54 cm, and densities of 30, 60, 90, 120, 150 and 180 seeds per linear meter. The experimental units were three meters wide by 10 meters long, totaling 30 square meters. The variables analyzed are divided into three morphological groups: plant height, height of insertion of the first capsule, number of branches at the base, stem diameter, number of stem branches, number of productive branches; productive variables: number of capsules per plant, capsule mass, number of capsules that formed grain, number of capsules that did not form grains, number of grains per plant, mass of grains per plant, mass of one thousand grains and grain yield; meteorological variables: rainfall (mm), minimum air temperature (°C) and maximum air temperature (°C). Grain yield reduces when growing at larger spacings. The highest expression of grain yield occurs in row spacing of 18 cm. Indirect selection for linseed grain yield can be performed through the number of stem branches, number of productive branches, number and weight of capsules and number of grains per plant.

Keywords: *Linum usitatissimum*, dissimilarity, linear correlation.

AJUSTE DO ARRANJO DE ÓTIMO PLANTAS PARA MAXIMIZAR A PRODUTIVIDADE E QUALIDADE DOS GRÃOS DE LINHAÇA

RESUMO - Compreender e explorar o potencial produtivo das culturas garante o retorno econômico e sustentabilidade da atividade. Além do melhoramento genético e eventos biotecnológicos, o manejo de práticas culturas contribui para a expressão do alto desempenho das culturas. O objetivo deste trabalho foi destacar os efeitos do espaçamento entre linhas e densidades de sementes no desempenho agronômico da linhaça. O ensaio foi desenvolvido na área experimental do Instituto Regional de Desenvolvimento Rural, pertencente à Universidade Regional do Noroeste do Estado do Rio Grande do Sul. O delineamento experimental foi em blocos casualizados, e os tratamentos foram estruturados em esquema fatorial três (espaçamentos) x seis (densidades) com três repetições por tratamento, totalizando 54 unidades experimentais. Foram utilizados três espaçamentos entre linhas, 18, 36 e 54 cm, e densidades de 30, 60, 90, 120, 150 e 180 sementes por metro linear. As unidades experimentais tinham três metros de largura por 10 metros de comprimento, totalizando 30

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metros quadrados. As variáveis analisadas dividem-se em três grupos, morfológicas: altura de plantas, altura da inserção da primeira cápsula, número de ramos da base, diâmetro do caule, número de ramos do caule, número de ramos produtivos; variáveis produtivas: número de cápsulas por planta, massa da cápsula, número de cápsulas que formaram grão, número de cápsulas que não formaram grãos, número de grãos por planta, massa de grãos por planta, massa de mil grãos e rendimento de grãos; variáveis meteorológicas: precipitação pluviométrica (mm), temperatura mínima do ar (°C) e temperatura máxima do ar (°C). O rendimento de grãos reduz quando o cultivo ocorre em espaçamentos maiores. A maior expressão da produtividade de grãos ocorre em espaçamento entre linhas de 18 cm. A seleção indireta para a produtividade de grãos da linhaça pode ser realizada por meio do número de ramos do caule, número de ramos produtivos, número e massa de cápsulas e número de grãos por planta.

Palavras-Chave: *Linum usitatissimum*, dissimilaridade, correlação linear.

INTRODUCTION

Flaxseed (*Linum usitatissimum* L.) is one of the most versatile and useful crops that has been cultivated for thousands of years (Tomassoni et al., 2013). Its nutraeutical characteristics and functional reference to the body make this culture become of great interest in food use for living beings. Its grains are used in the textile, cosmetics, animal feed industry for providing more than 20% of crude protein, and they can be a source of clean energy as biodiesel.

According to Tomassoni et al. (2013), several factors interact and interfere in the expression of the productive potential of flaxseed, among which we can highlight the sowing process, the adequate choice of plant arrangement, and density, which reflect in the increase or decrease of interception and use of solar radiation. The thickening of plants and the reduction of spacing between rows promote greater absorption of light in the red band and greater reflection in the extreme red band (Tomassoni et al., 2013). In Brazil, the recommended sowing density is 120 plants per square meter when the goal is the production of fibers, while 90 plants per square meter is recommended to increase grain production (Stanck et al., 2017).

The distance between rows and the density of plants are substantial factors in the management of the crop. Understanding how these managements modulate plant growth and influence yield components can facilitate the use of new culture practices. Interactions between plants are altered when row spacing is modified. These interactions involve the competition for resources (Alzueta et al., 2012), as well as active morphogenetic responses triggered by the perception of neighboring plants.

Studies carried out by Ačko & Trdan (2008), show that row spacing of 0.17 m promotes the expression of higher grain yield and linseed ramifications. While Sarkees & Mahmood (2018), observed that 0.30 m between rows provided the best crop performance. Tomassoni et al. (2013) observed maximum yields of flaxseed grains with population densities of 200 and 400 plants per square meter. In one of their works, Tomassoni et al. (2013) also found that the number of capsules doubled when the population went from 400 to 900 seeds per square meter. Rossi et al. (2014) showed a reduction in flaxseed grain yield in densities lower than 99 seeds per square meter.

Studies of plant density are important because it is one of the culture practices that most affects crop yield, but when dealing with the flaxseed culture these studies are scarce. In this context, the aim of this work was to highlight the effects of row spacing and seed densities on the agronomic performance of flaxseed.

MATERIAL AND METHODS

The trial was developed in the experimental area of the Regional Institute of Rural Development, which belongs to the Regional University of the Northwest of the Brazilian State of Rio Grande do Sul, located in the city of Augusto Pestana (RS), at 28° 26’ 20’ S and 54° 00’ 23’ W, at an approximate altitude of 301 meters. The soil of the experimental area is classified as Typical Dystropheric Red Latosol. According to Köppen, the climate is characterized as *Cfa* (humid subtropical). The experimental design was randomized blocks, and the treatments were structured in factorial scheme three (spacings) X six (densities) with three replications per treatment, totaling 54 experimental units. We used three spacings between rows, 18 cm, 36 cm and 54 cm, and densities of 30, 60, 90, 120, 150 and 180 seeds per linear meter. The experimental units were three meters wide by 10 meters long, totaling 30 square meters.

Sowing was carried out on May 28, 2020 and the fertilizer used was 260 kg ha^{-1} formula 5-20-20 (N-P-K). Cover fertilization was performed with urea at 30 days after emergence, using 45 kg. ha^{-1} nitrogen. The flaxseed genotype used was IJUI001 with a total cycle of 160 days. Culture treatments were performed in a standardized way in all treatments in order to reduce damage by biotic factors. An insecticide application was carried out at the vegetative stage and another at the grain filling stage, as well as a fungicide application at the vegetative stage. The approximate rainfall during the experimental period, 167 days, was 866 mm. The linseed harvest was carried out in the second half of October.

In the useful area of each experimental unit, in ten representative plants, the following traits were measured: plant height (PH, cm), the height of the first capsule insertion (HFCI, cm), number of base branches (NBB, unit), stem diameter (SD, mm), number of stem branches (NSB, unit), number of productive branches (NPB, unit), number of capsules (NCAP, unit), capsule mass (CPM, grams), number of capsules that formed grains (NCFG, unit), number of capsules that did not form grains (NCNFG, unit), number of grains per plant (NGP, unit), grain mass per plant (GMP, grams), mass of one thousand grains (MTG, grams), and grain yield (GY, kg). The meteorological data on rainfall and temperature were obtained from the weather station at the Regional Institute for Rural Development.

The data obtained were subjected to the assumptions of the statistical model, normality and homogeneity of residual variances and additivity of the model. Subsequently, a descriptive analysis was carried out, and an analysis of variance at 5% probability was performed by the F test. The interaction between seed densities per linear meter x row spacing was tested. The variables that showed a significant interaction were dismembered to simple effects through a polynomial linear regression with a significant degree based on the *t* test at 5% probability.

The significant quadratic phenomena were subjected to the estimate of the maximum technical efficiency through the ratio between the linear and quadratic coefficients. In order to identify the tendency of association between traits, the Pearson's linear correlation was determined at 5% probability. Also, proceeded the study of divergence between treatments through cluster analysis using as a measure of dissimilarity to Euclidean distance. After obtaining the matrix of Euclidean distances, the UPGMA clustering method was used to generate the dissimilarity dendrogram in order to recognize homogeneous groups.

The economic return calculations were carried out with the cultivation of linseed in different spacings, taking into account the grain sales values, acquisition costs of inputs and gross value per hectare of the year of the study, in order to understand through economic parameters, the effects of plant arrangements. All statistical analyses were performed by the software R (R Core Team, 2022), using packages *Ggplot2* (Wickham, 2016), *Metan* (Olivoto & Lúcio, 2020), *Agricolae* (Mendiburu, 2021) and *ExpDes.pt* (Ferreira et al., 2021).

RESULTS AND DISCUSSION

For flaxseed, the need for water for normal plant growth and development varies between 400 and 750 mm (Becker, 2018). The approximate rainfall during the experimental period, 167 days, was 866 mm (Figure 1), which was well distributed in June and July, with greater accumulation in the latter. However, August and especially September and October were marked by low and poorly distributed rainfall. The optimum air temperatures for the flaxseed cycle fluctuate according to the development stage; in the emergence stage to the beginning of flowering it was 2.0 °C, and in the stage at the beginning of flowering to the harvest it was 4.8 °C. Temperatures above 30 °C have a negative influence on the production of flaxseed and extremes below -5 °C in the vegetative stage or below –1 °C in the reproductive stage cause irreversible damage to the plants (Becker, 2018). In this trial, the temperatures in the initial stage of the culture were mild; however, localized frosts occurred in June, 2.4 °C, without severity to the plants. Low temperatures with more intense frosts occurred in July and August, with minimums of -1.8 °C and -2.4 °C, respectively, without damage to the plants, since they were in the vegetative stage. From September onwards, temperatures increased with maximum averages of 24.51 °C, 29.6 °C and 30.2 °C in September and October, respectively, coinciding with the filling of flaxseed grains, which may have promoted the reduction of some yield components. High temperatures in grain filling result in a high rate of plant respiration, reduced photoassimilated storage, thus reducing the grain yield of flaxseed (Saghayesh et al., 2014).

The agronomic performance of genotypes in different plant arrangements is reflected in the net return value to producers (Figure 2), since the highest economic result is observed in the 18 cm arrangement between rows with 180 seeds per linear meter, with values above BRL 13,000.00 per hectare, even with the highest sowing cost verified in this arrangement, which leads to the greatest grain yield in this treatment. It should be noted that this arrangement exhibited a net return of approximately 18% higher than the second best economic return.

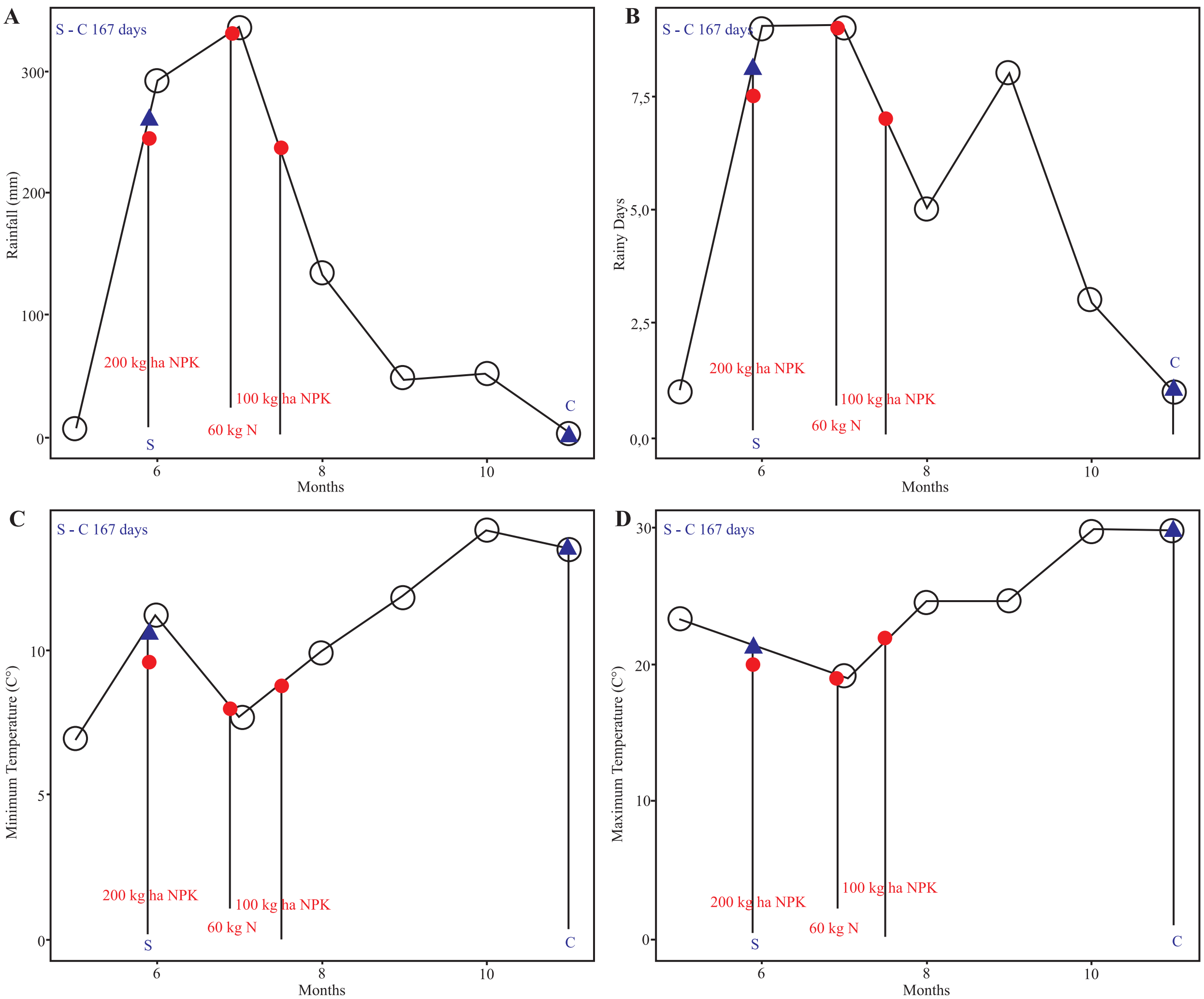

Figure 1 **-** Climate data from the meteorological station of the Regional Institute for Rural Development (IRDeR) during the development cycle of the flaxseed culture (167 days). A: Rainfall; B: Rainy days; C: Minimum air temperature (°C); d: Maximum air temperature (°C).

The costs for sowing flaxseed in different arrangements (Figure 3) were higher in the densities of 180 seeds per linear meter in all row spacings used, while lower costs were in the lowest density of plants per linear meter in all spacings. The highest cost among all treatments was the spacing of 18 centimeters between rows with 180 seeds per linear meter, evidently due to the greatest final seed population used, that is, the higher the seed density the higher the cost per hectare.

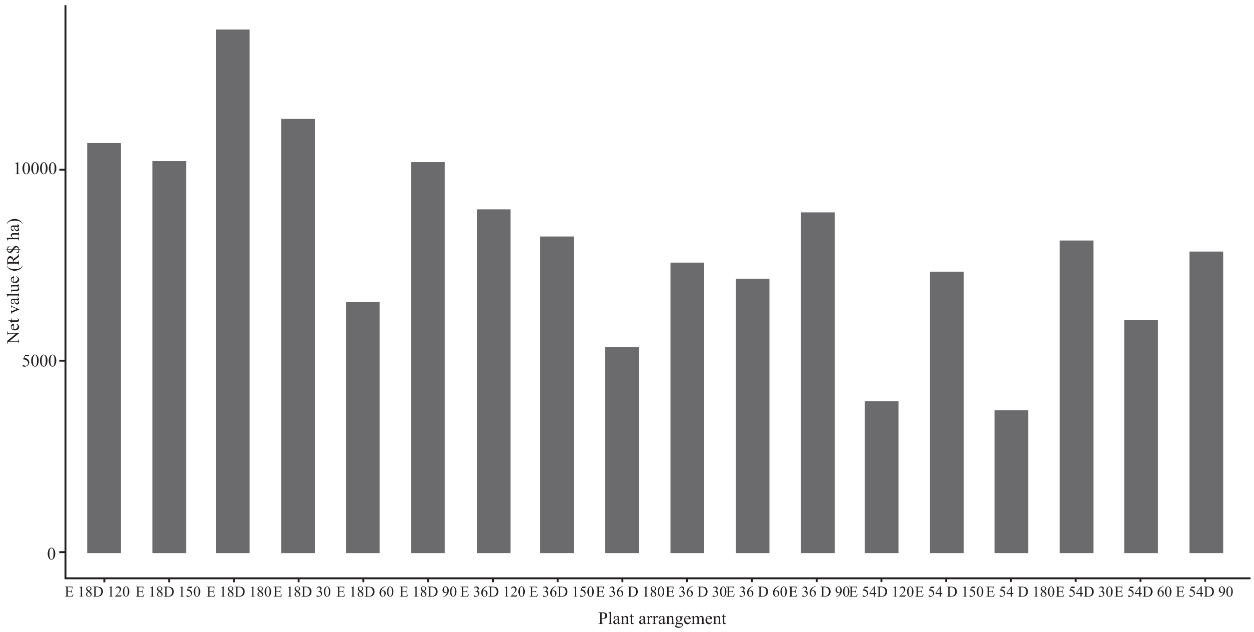

Figure 2 - Description of net yield per hectare of flaxseed in three row spacings and six seed densities per linear meter. Augusto Pestana – Rio Grande do Sul, 2020. E18D120 - 18 cm spacing with a density of 120 seeds per linear meter; E18D150 - 18 cm spacing with a density of 150 seeds per linear meter; E18D180 - 18 cm spacing with a density of 180 seeds per linear meter; E18D30 - 18 cm spacing with a density of 30 seeds per linear meter; E18D60 - 18 cm spacing with a density of 60 seeds per linear meter; E18D90 - 18 cm spacing with a density of 90 seeds per linear meter; E36D120 - 36 cm spacing with a density of 120 seeds per linear meter; E36D150 - 36 cm spacing with a density of 150 seeds per linear meter; E36D180 - 36 cm spacing with a density of 180 seeds per linear meter; E36D30 - 36 cm spacing with a density of 30 seeds per linear meter; E36D60 - 36 cm spacing with a density of 60 seeds per linear meter; E36D90 - 36 cm spacing with a density of 90 seeds per linear meter; E54D120 - 54 cm spacing with a density of 120 seeds per linear meter; E54D150 - 54 cm spacing with a density of 150 seeds per linear meter; E54D180 - 54 cm spacing with a density of 180 seeds per linear meter; E54D30 - 54 cm spacing with a density of 30 seeds per linear meter; E54D60 - 54 cm spacing with a density of 60 seeds per linear meter; E54D90 - 54 cm spacing with a density of 90 seeds per linear meter.

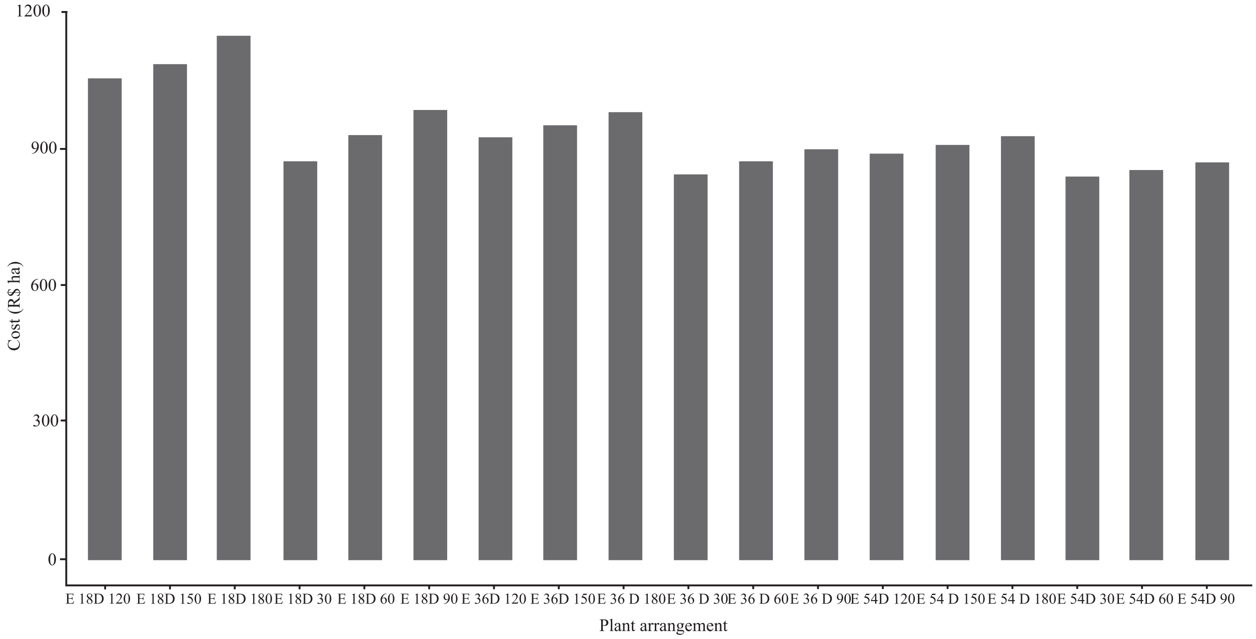

Figure 3 - Description of the costs per hectare of flaxseed in three row spacings and six seed densities per linear meter. Augusto Pestana – Rio Grande do Sul, 2020. E18D120 - 18 cm spacing with a density of 120 seeds per linear meter; E18D150 - 18 cm spacing with a density of 150 seeds per linear meter; E18D180 - 18 cm spacing with a density of 180 seeds per linear meter; E18D30 - 18 cm spacing with a density of 30 seeds per linear meter; E18D60 - 18 cm spacing with a density of 60 seeds per linear meter; E18D90 - 18 cm spacing with a density of 90 seeds per linear meter; E36D120 - 36 cm spacing with a density of 120 seeds per linear meter; E36D150 - 36 cm spacing with a density of 150 seeds per linear meter; E36D180 - 36 cm spacing with a density of 180 seeds per linear meter; E36D30 - 36 cm spacing with a density of 30 seeds per linear meter; E36D60 - 36 cm spacing with a density of 60 seeds per linear meter; E36D90 - 36 cm spacing with a density of 90 seeds per linear meter; E54D120 - 54 cm spacing with a density of 120 seeds per linear meter; E54D150 - 54 cm spacing with a density of 150 seeds per linear meter; E54D180 - 54 cm spacing with a density of 180 seeds per linear meter; E54D30 - 54 cm spacing with a density of 30 seeds per linear meter; E54D60 - 54 cm spacing with a density of 60 seeds per linear meter; E54D90 - 54 cm spacing with a density of 90 seeds per linear meter.

The gross value per hectare (Figure 4) revealed the same tendency as the net value, with superiority in the arrangement of 18 cm between rows with 180 seeds per linear meter with a value close to BRL 15,000.00 per hectare; however, the lowest gross value is observed in the spacing of 54 cm with 180 seeds per linear meter, probably due to low yield because of the high competition between plants in the sowing line.

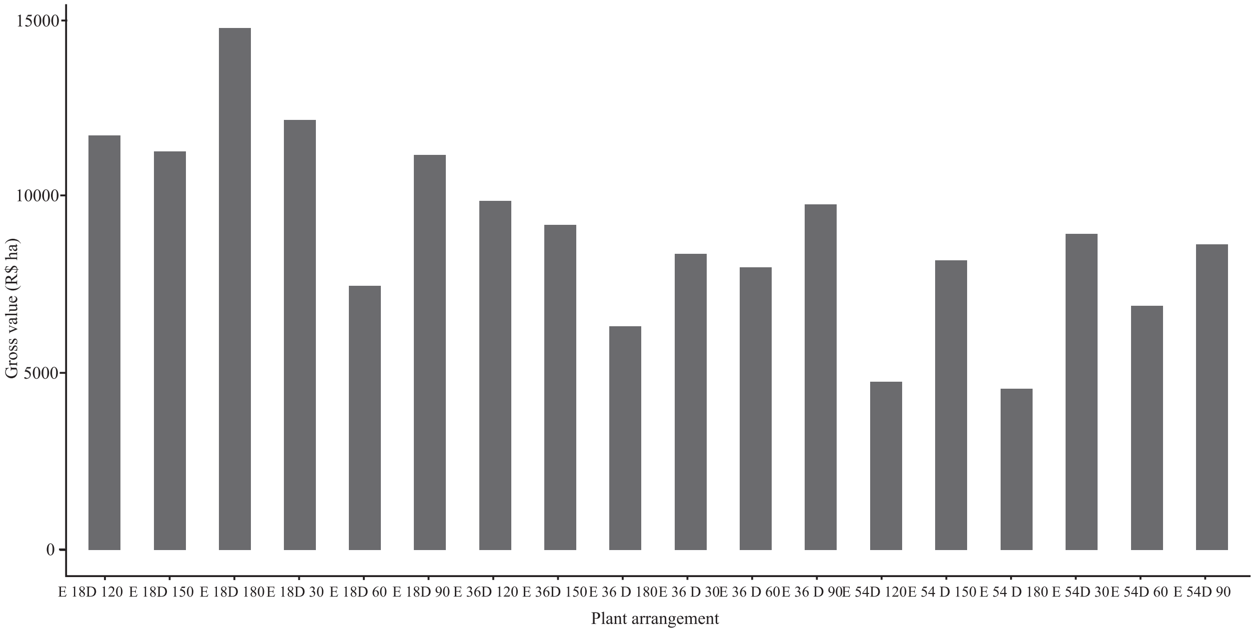

Figure 4 - Description of the gross value per hectare of flaxseed in three row spacings and six seed densities per linear meter. Augusto Pestana – Rio Grande do Sul, 2020. E18D120 - 18 cm spacing with a density of 120 seeds per linear meter; E18D150 - 18 cm spacing with a density of 150 seeds per linear meter; E18D180 - 18 cm spacing with a density of 180 seeds per linear meter; E18D30 - 18 cm spacing with a density of 30 seeds per linear meter; E18D60 - 18 cm spacing with a density of 60 seeds per linear meter; E18D90 - 18 cm spacing with a density of 90 seeds per linear meter; E36D120 - 36 cm spacing with a density of 120 seeds per linear meter; E36D150 - 36 cm spacing with a density of 150 seeds per linear meter; E36D180 - 36 cm spacing with a density of 180 seeds per linear meter; E36D30 - 36 cm spacing with a density of 30 seeds per linear meter; E36D60 - 36 cm spacing with a density of 60 seeds per linear meter; E36D90 - 36 cm spacing with a density of 90 seeds per linear meter; E54D120 - 54 cm spacing with a density of 120 seeds per linear meter; E54D150 - 54 cm spacing with a density of 150 seeds per linear meter; E54D180 - 54 cm spacing with a density of 180 seeds per linear meter; E54D30 - 54 cm spacing with a density of 30 seeds per linear meter; E54D60 - 54 cm spacing with a density of 60 seeds per linear meter; E54D90 - 54 cm spacing with a density of 90 seeds per linear meter.

The analysis of variance (Table 1) revealed no significant interactions between row spacing x seed density per linear meter for all variables. The absence of a significant interaction between row spacing x plant density per linear meter was also observed by Nielsen (1988) and Cox et al. (1998) and by Porter et al. (1997) in studies with corn. However, variables final plant population per hectare (FPH) and grain yield (GY) showed a significant response ($p<0.05$) to row spacing, showing a linear response. Productivity depends on soil and climate factors, while the response to population density is highly dependent on limiting factors such as water and nutrients (Amin et al., 2015).

Table 1 - Summary of the analysis of variance for three row spacings and six seed densities per linear meter of flaxseed. Augusto Pestana – Rio Grande do Sul, 2020.

FV	GL	Pr>Fc							
		HFCI	PH	SD	PI	CPM	GMP	MTS	NCP
Block	2	0.04451	0.23814	0.24456	0.14013	0.14441	0.30123	0.50731	0.21174
Spacing (S)	2	0.20332	0.16828	0.38217	0.67973	0.42072	0.73472	0.61173	0.3977
Density (D)	5	0.75925	0.73451	0.00008*	0.00001*	0.01406*	0.02466*	0.59012	0.02191*
S x D	10	0.41212	0.07913	0.37202	0.22702	0.97373	0.99363	0.4433	0.97941
Residue	34								
Total	53								
CV (%)		7.2	7.2	12.39	23.37	24.63	25.42	3.54	23.43
FV	GL	Pr>Fc							
		NCFG	NSB	NBB	NPB	NGP	FPH	GY	
Block	2	0.18022	0.33451	0.54067	0.73527	0.46536	0.120012	0.46401	
Spacing (S)	2	0.2696	0.11067	0.21297	0.38618	0.61338	0.00001*	0.00068*	
Density (D)	5	0.02103*	0.00708*	0.37245	0.00132*	0.01924*	0.010772*	0.55876	
S x D	10	0.98021	0.95529	0.63464	0.98912	0.9638	0.164184	0.27201	
Residue	34								
Total	53								
CV (%)		13.58	28.71	27.12	22.82	29.13	28.99	24.9	

*Height of first capsule insertion (HFCI, cm), plant height (PH, cm), stem diameter (SD, mm), plasticity index (PI, %), capsule mass (CPM, g), grain mass per plant (GMP, g), mass of one thousand grains (MTS, g), number of capsules per plant (NCP), number of capsules that formed grains (NCFG), number of stem branches (NSB), number of basal branches (NBB), number of productive branches (NPB), number of grains per plant (NGP), final plant population per hectare (FPH) and grain yield (GY).

Stem diameter, plasticity index, capsule mass, grain mass per capsule, number of total capsules per plant, number of capsules that formed grains, number of stem branches, number of productive branches, number of grains per plant and final population of plants per hectare showed significant responses due to the different densities of plants per linear meter, mostly presenting a linear behavior, except for the number of productive branches and the plasticity index, which revealed a quadratic response, and stem diameter, which showed a cubic behavior. Sarkees & Mahmood (2018), evaluating seeding densities, observed similar results, in which the stem diameter expressed a different variation from the linear one as the plant density increased. This shows that other factors may also be involved in the expression of this character.

The height of the first capsule insertion, plant height, mass of a thousand grains and number of branches at the base were not influenced by the spacing or by plant density, indicating mainly constant performance of these traits in the plant arrangements. Tomassoni et al. (2013) studied the effect of flaxseed densification of 100, 150, 200 and 250 plants per m^2, not reporting significant differences with respect to plant height, as well as Santos et al. (2016) in flaxseed and Ambile et al. (2002) in ginger, who did not show the influence of population density on plant height.

The coefficients of variation were considered low for the traits that were not influenced by the factors of variation; however, the other traits revealed values above 12%, probably due to the great performance of the factors of variation on the expression of these traits. Similarly, Cargnelutti Filho et al. (2016) report a coefficient of variation of 8.60 for trait plant height.

Through the analysis of Pearson's linear correlation (Figure 5), the correlations between the tested variables can be identified, so that the correlation values range from -1 (strong and negative correlation) to 1 (strong positive correlation). The Pearson's linear correlation coefficients (r) between traits showed some positive linear associations. This means that the highest scores of certain traits are associated with the highest scores of others. This pattern of linearity between traits is important to identify traits for indirect selections (Cargnelutti Filho et al., 2016). It can be seen (Figure 5) that high magnitude correlations have a greater emphasis on the correlation coefficient in the figure to facilitate understanding and identify the most important associations.

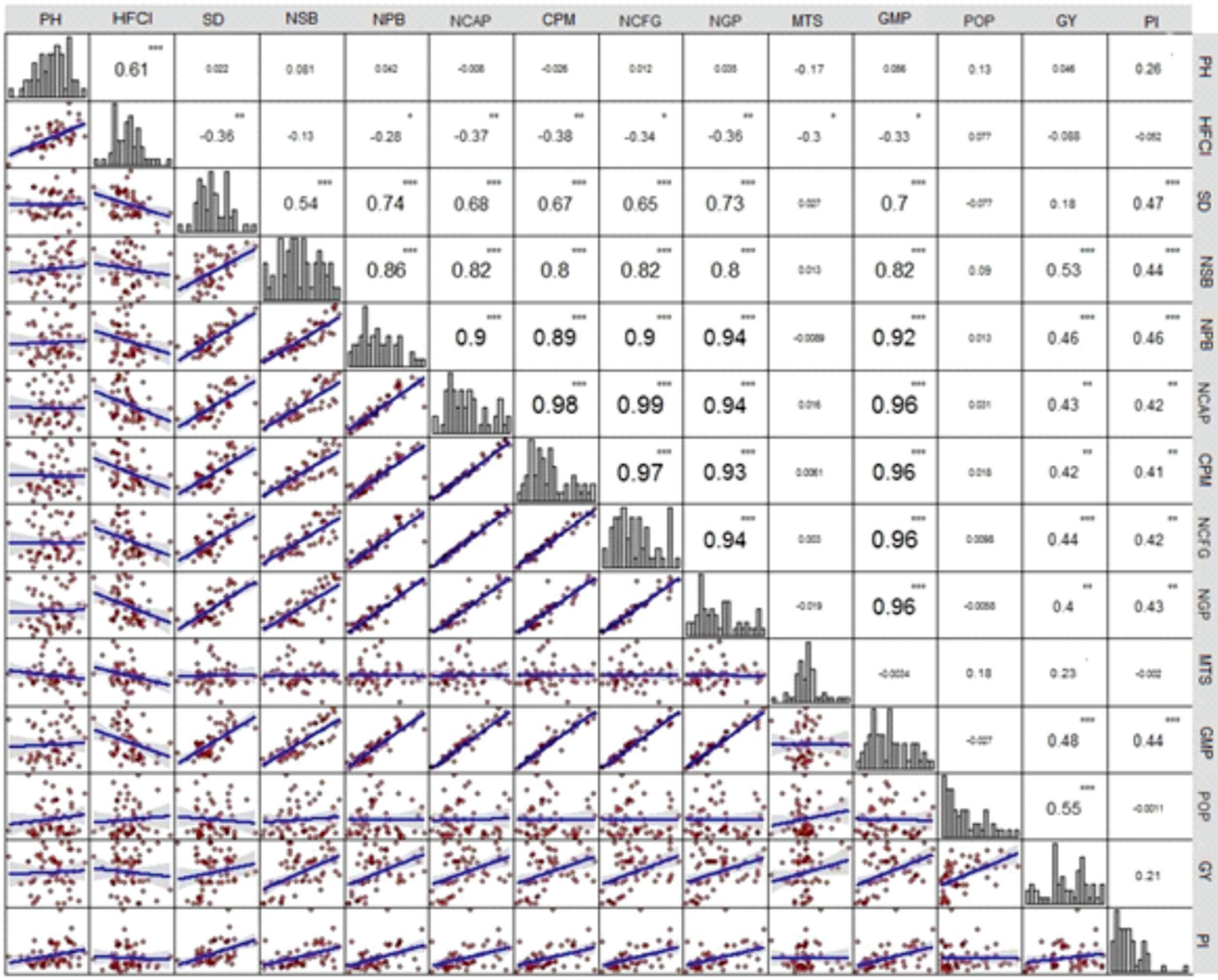

Figure 5 - Pearson's linear correlation estimates for the traits evaluated in three row spacings and six seed densities per linear meter significant at 5*, 1**, 0.01% *** error probability. Plant height (PH, cm), height of first capsule insertion (HFCI, cm), stem diameter (SD, mm), number of stem branches (NSB), number of capsules (NCAP), capsule mass (CPM, g), number of capsules that formed grains (NCFG), number of capsules per plant (NCP), mass of one thousand seeds (MTS), grain mass per plant (GMP, g), final plant population (POP), grain yield (GY), plasticity index (PI). Augusto Pestana – Rio Grande do Sul, 2020.

A positive association of a high magnitude is observed between plant height and the height of the first capsule insertion. Thus, it can be inferred that taller flaxseed plants are associated with plants with greater height of the first capsule insertion. However, the latter exhibits a negative correlation with the mass of grains per plant, mass of a thousand seeds, number of capsules that formed grains, capsule mass per plant, number of productive branches and stem diameter.

Cargnelutti Filho et al. (2016) showed a positive relationship between plant height and shoot green mass without capsules. This may explain the negative relationships evidenced in the study, since taller plants tend to express greater development of vegetative organs and less expression of characteristics directly associated with grain yield. In this situation, plants tend to direct a greater amount of photoassimilates for vegetative development (Taiz et al., 2017).

This way, it is possible to deduce that plants with greater height of capsule insertion are related to plants with limited yield components. Plants with greater height of the first capsule insertion tend to exhibit greater total plant height, and this may be indirectly associated with the plant population, since greater densification can limit resources such as luminosity, water and nutrients, promoting an intraspecific competition, which reduces the yield components of flaxseed. However, further studies are needed to understand the dynamics of the association of these traits.

A positive association was observed in relation to stem diameter and traits plasticity index, grain mass per plant, number of grains per plant, number of capsules that formed grains, number of productive branches, indicating that plants with thick stems are related to plants with a higher number of grains, capsules and productive branches, possibly due to the association with the number of productive branches, which promotes the thickening of the stem to promote greater sustainability of the plant. Thus, the more productive branches the greater the production of the yield components of flaxseed.

The number of stem branches and the number of productive branches expressed a positive intermediate correlation with the plasticity index and grain yield, since the branches present increase the number of the other yield components; this is proven by the strong positive correlation of the number of stem and productive branches with grain mass per plant, number of grains per plant, number of capsules that formed grains, mass of capsules and number of capsules. Results corroborate with Siddiqui et al. (2016), who showed a positive correlation between branches, grain yield, number of capsules per plant and number of productive branches.

A positive correlation was revealed for the number of capsules with the plasticity index, grain yield, grain mass per plant, number of grains per plant, number of capsules that formed grains and capsule mass. Siddiqui et al. (2016), Naik et al. (2016) and Dash et al. (2016) inferred that the number of capsules is one of the traits with great contribution in grain yield. Likewise, the mass of capsules exhibited an intermediate positive correlation with the plasticity index, grain yield and a strong correlation with grain mass per plant, number of grains per plant and number of capsules that formed grains. Similarly, the number of capsules that formed grains correlated in an intermediate way with the plasticity index and grain yield, and had a strong correlation with grain mass per plant and number of grains per plant. In addition, several studies have also identified positive correlations with the number of capsules that formed grains with flaxseed grain yield (Naik & Satapathy, 2002; Rao, 2007; Gauraha & Rao, 2011).

Also, the number of grains per plant revealed a positive intermediate correlation with the plasticity index and grain yield; however, there was a similar strong correlation in the same direction with grain mass per plant. The results highlighted in the present study are confirmed by Dash et al. (2016), who also inferred an association of the number of grains per plant with grain yield. In turn, the mass of grains per plant had a positive intermediate correlation with the plasticity index and grain yield and the latter correlated in a positive way with the final population of plants per hectare.

The study of dissimilarity between treatments allows a simpler understanding of trends in the effects of treatments on the study variables. The dendrogram obtained from the dissimilarity matrix generated from the measured traits (Figure 6) allowed the formation of five distinct groups, being an arrangement attributed to Group 1, four to Group 2, two to Group 3, three to Group 4 and eight to Group 5. The treatments that diverged the most were the members of Group 1, formed by arrangement 6, and those of Group 5, formed by arrangements 9, 10, 7, 8, 17, 11, 13 and 15.

With this, it can be inferred that group 1 (E18D180) promoted the expression of characteristics that differentiate it with great magnitude from group 5. It is known that the best performance of the culture occurred when the plants were evaluated in the E18D180 arrangement. Therefore, through the dendrogram, it can be verified that in case of difficulties in using the density of 180 plants per linear meter, the densities that are similar to this are those of group 2.

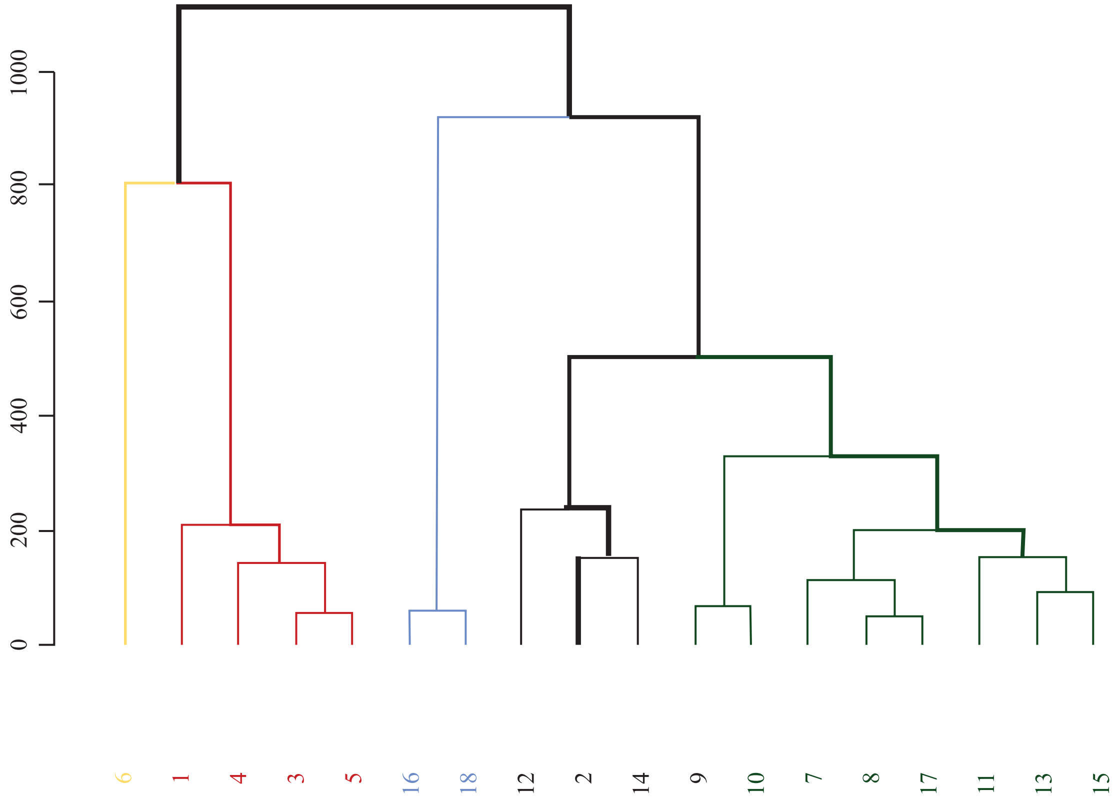

Figure 6 - Dendrogram with dissimilarity using the standardized Euclidean distance, obtained by the average binding method (UPGMA), Augusto Pestana – Rio Grande Estado do Sul, 2020. 1: E18D30; 2: E18D60; 3: E18D90; 4:E18D120; 5: E18D150; 6: E18D180; 7: E36D30; 8: E36D60; 9: E36D90; 10:E36D120; 11: E36D150; 12: E36D180; 13: E54D30; 14: E54D60; 15: E54D90; 16:E54D120; 17: E54D150; 18: E54D180.

The regression analysis (Figure 7) showed a strong linear influence of seed density per linear meter on the number of capsules per plant; the equation shows that the density coefficient of plants per linear meter is 38.11; the coefficient indicates that, for each additional unit of seeds per linear meter, it can be expected that the number of capsules reduces, on average, 0.1043 units. Santos et al. (2016) showed the same tendency to reduce traits due to the increase in plant density, and Casa et al. (1999) showed that flaxseed shows a compensatory capacity, mainly through the production of a greater number of capsules when at reduced densities, and the other way round as plant density was increased. The same behavior occurs with the number of capsules that formed grains, number of branches, number of grains per plant, mass of capsules per plant and mass of grains per plant. These traits showed better results when in environments with low plant densities; however, they respond negatively in 0.0936, 0.0273, 0.7431, 0.0055 and 0.0037 units to each seed that is increased in the sowing line, all with determination coefficients greater than 0.70.

The regression analysis (Figure 8) showed that stem diameter had a cubic response to seed density per linear meter. These results suggest that this trait may vary according to the densities used, in which a superior response was observed in the lowest density (30 seeds); however, the lowest result was found in the density of 180 seeds per linear meter, with a similar behavior between 60 and 90 seeds per linear meter. Sarkees & Mahmood (2018) showed similar results for the stem diameter response.

This trait is of extreme importance, since flaxseed plants are subject to lodging, depending on soil and climate conditions; greater growth in diameter is an important trait agronomically because it is related to greater resistance to the bending of plants (Linzmeyer Junior et al., 2008;

Vasquez et al., 2008). The plasticity index showed a quadratic behavior, so that there was a decrease in this index due to the increase of seeds until the density of 150 seeds per linear meter, in which it exhibited a point of minimum plasticity.

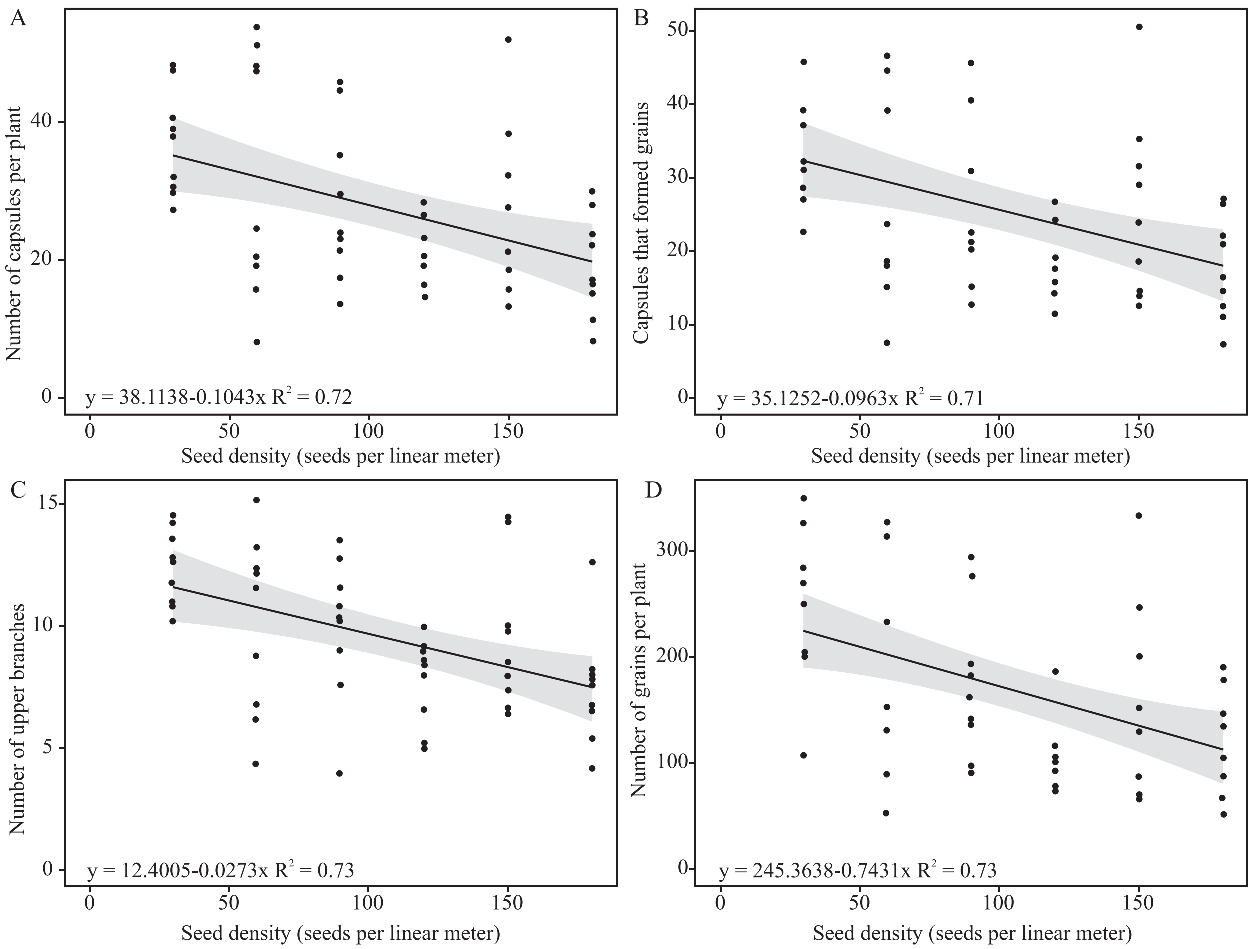

Figure 7 - Linear regressions for number of capsules per plant (A), capsules that formed grains (B), number of upper branches (C) and number of grains per plant (D) in six seed densities per linear meter, significant at 5% error probability.

Regarding parameter mass of the capsules and number of capsules per plant, both were higher in lower densities, with degrowth as the density of flaxseed sowing increased, agreeing with results of Nadaletti et al. (2014), who observed that lower densities provide a greater number of capsule mass per plant. Similarly, Cecon et al. (2004) observed a reduction of some components of grain yield of white oat in dense environments. Hassan et al. (20005) showed similar responses of productive characters in relation to the increase in plant density.

Thus, it can be inferred that the increase in plant density tends to promote greater competition between plants. This competition occurs for space, nutrients, water, radiation. This triggers less efficient physiological processes in the production of photoassimilates, since the absorption of nutrients, water and photons of solar energy are limited by competition (Taiz et al., 2017). This explains the reduction of most of the direct components of crop productivity.

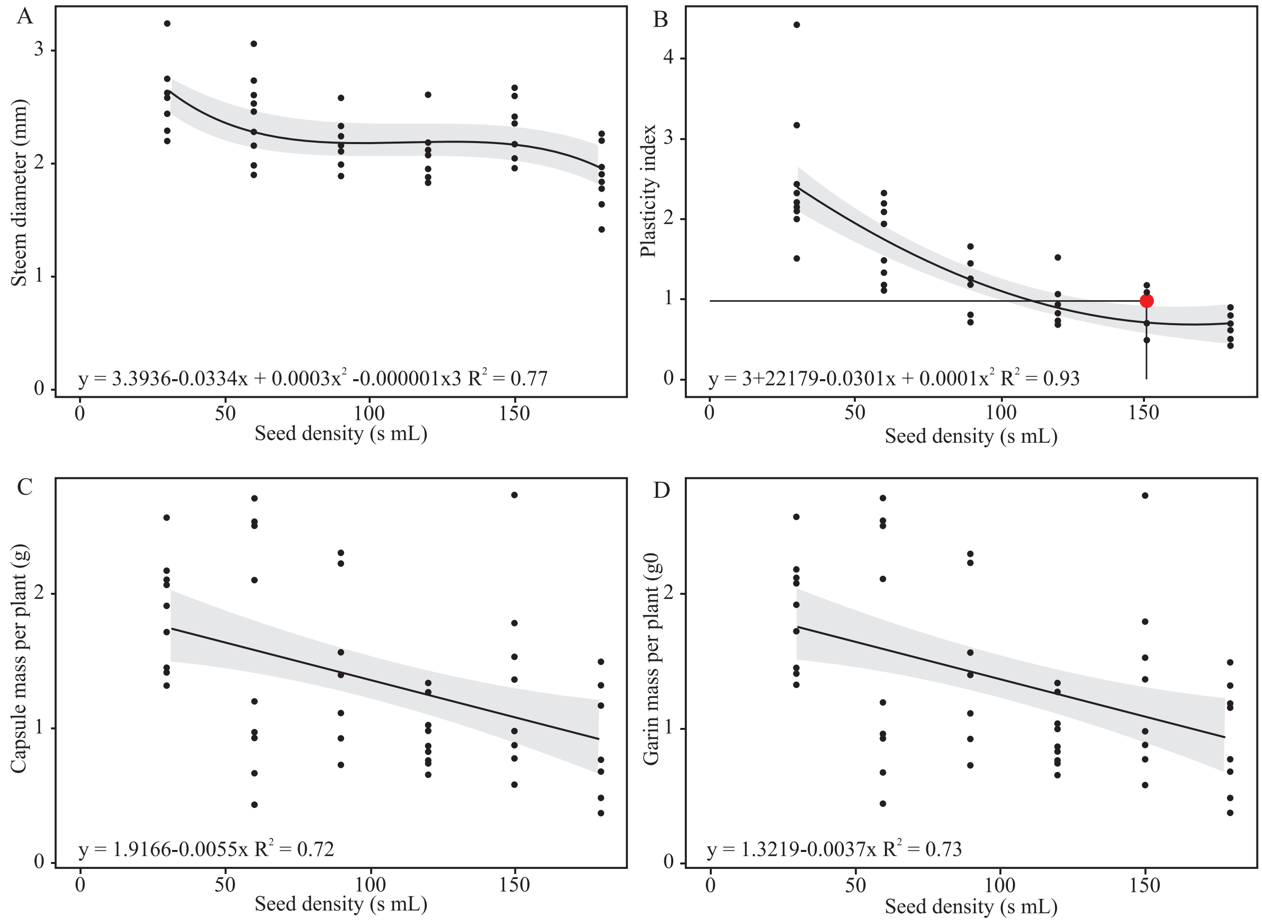

Figure 8 - Cubic polynomial regression for stem diameter (A), quadratic polynomial regression for the plasticity index (B), and significant linear regressions at 5% probability for traits capsule mass per plant (C) and grain mass per plant (D) in response to six seed densities per linear meter, significant at 5% error probability.

Evidently, row spacing and plant density demonstrated a linear influence on the plant population, since smaller spacings allow a greater occupation of the area to be sown, increasing the number of rows per hectare when compared with other spacings, in the same way as higher row densities promote a greater number of plants per unit of area (Figure 9). The number of productive branches presented a quadratic behavior in response to seed density, in such a way that there was a reduction in the number of branches due to the increase in density up to approximately 130 seeds; from this density onwards, it was verified that the trait was stabilized.

Although plant density per linear meter has an influence on a large part of the yield components, row spacing was responsible for the change in grain yield; this can be explained because seeding in smaller spacings tends to have a smaller distribution of plants in the same line, thus, intraspecific competition is lower, which contributes to a better agronomic performance of the crop (Ačko & Kocjan, 2008). The reduction in spacing between seeding rows reduces intraspecific competition in the furrow and provides the plant with a more equidistant arrangement, allowing more space for the roots to exploit water and nutrients. In addition, the cultivation of flaxseed in reduced rows and high plant density can promote the control of invasive plants (Braz et al., 2019).

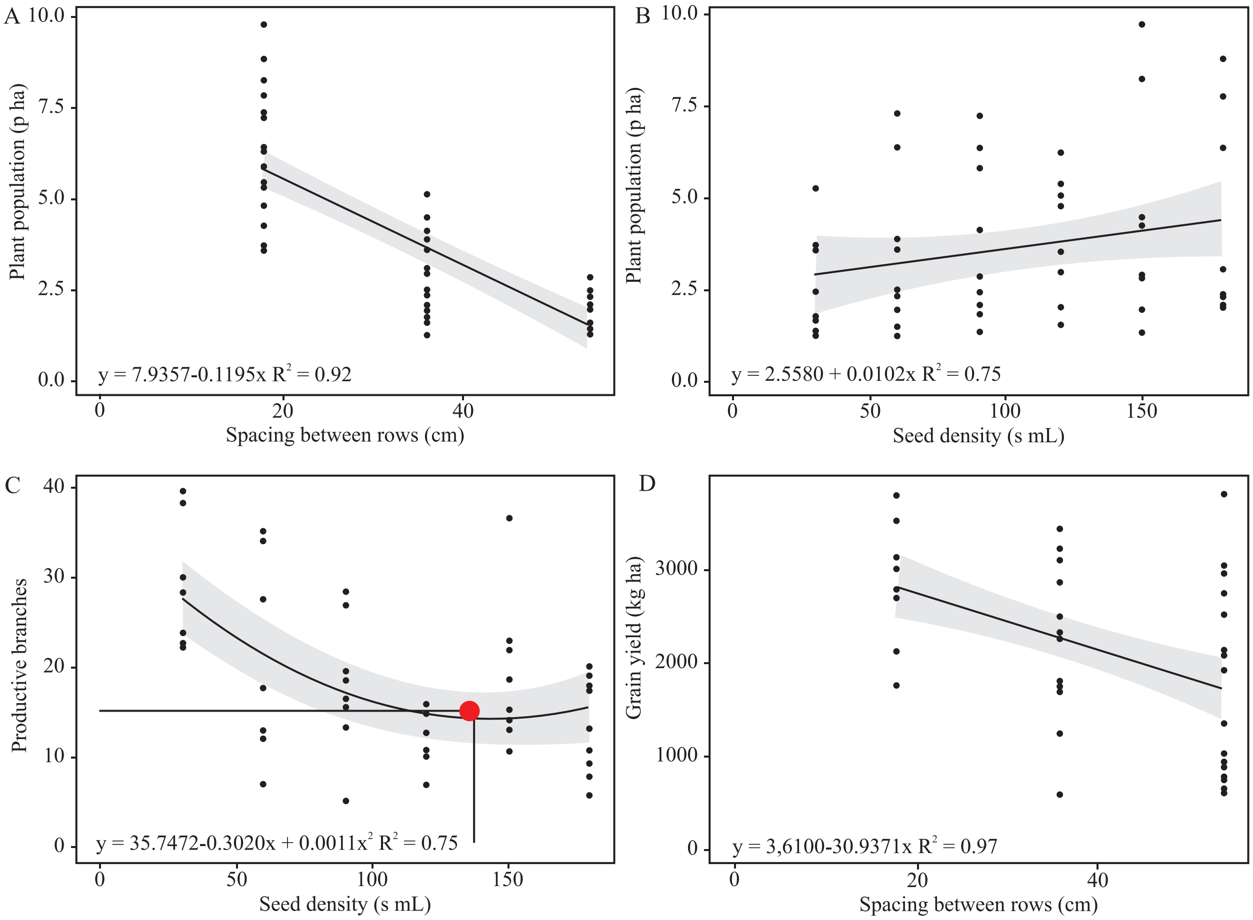

Figure 9 - Linear polynomial regression for plant population and spacing between rows (A) and plant population and seed density (B). Quadratic regression for productive branches and seed density (C), and linear regression between grain yield and row spacing (D), significant at 5% error probability.

In this study, it is observed the strong negative impact that the increase in seed density per linear meter has on the number of capsules, capsules that formed grains, number of branches, number of grains per plant, stem diameter, plasticity index, mass of capsules per plant, mass of grains per plant and productive branches. There is no evidence of any advantage in adjusting plant density to up or down as the distance between rows decreases from 54 to 18 cm. The same was verified by Rossi et al. (2014), who did not observe significant differences in flaxseed grain yield when altering seed density. However, they showed a favorable advantage for row spacings of 18 cm over 54 cm spacings in all plant densities tested. In addition, they observed that as plant density per linear meter increased, the flaxseed yield components decreased. However, flaxseed tended to perform better in the environment with narrow rows (18 cm), which leads to the hypothesis that the number of plants per unit of area is the main component of grain yield of the flaxseed culture.

CONCLUSION

Increased spacing contributes to reduced grain yield regardless of the sowing density.

The row spacing of 18 cm shows the best results for grain yield in relation to the seed densities used.

High magnitude linear associations such as number of stem branches, productive branches, number and mass of capsules and grains per plant, and plant population define grain yield per unit of area.

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Recebido para publicação em 10/05/2022, aprovado em 08/06/2022 e publicado em 30/07/2022.