Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Spatial arrangement for sesame cultivars

Arranjo espacial para cultivares de gergelim

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Submission: November 11, 2024 | Acceptance: April 19, 2025

ABSTRACT

This research evaluated the impact of different population densities and spacing on the agronomic characteristics of the Trebol and K3 sesame cultivars. The experiment was conducted at EMPAER's experimental unit in Cáceres, between March and July 2022, using randomized block design with twelve treatments and three replications. The treatments varied in spacing between 0.20 and 0.80 meters between the rows, and the characteristics analyzed included plant height, insertion of the first pod, number of pods per plant, number of seeds per pod, estimated yield, lodging index, purity analysis, determination of the weight of a thousand seeds, germination test and first germination count and germination speed index. The results indicated that the 0.80 m spacing favored plant development, especially related to height and number of pods, with the K3 cultivar standing out as the most productive. The phenotypic correlation analysis showed that the lodging index was the most relevant variable in determining the productivity of the Trebol cultivar, while plant height was the main variable for the K3 cultivar. It concluded that the 0,80 m row spacing is beneficial for sesame productivity, especially for the K3 cultivar, and that plant density directly influences the architecture and productive efficiency of the cultivars evaluated.

KEYWORDS: Sesamum indicum. Population density. Productivity.

RESUMO

Nesta pesquisa foi avaliado o impacto de diferentes densidades populacionais e espaçamentos nas características agronômicas dos cultivares de gergelim Trebol e K3. O experimento foi conduzido na unidade experimental da EMPAER, em Cáceres, entre março e julho de 2022, utilizando delineamento em blocos casualizados com 12 tratamentos e três repetições. Os tratamentos variaram entre espaçamentos de 0,20 e 0,80 metros entre linhas, e as características analisadas incluíram altura de plantas, inserção da primeira cápsula, o número de cápsulas por planta, número de sementes por cápsula, produtividade estimada, índice de acamamento, análise de pureza, determinação do peso de mil sementes, teste de germinação, primeira contagem de germinação e o índice de velocidade de germinação. Os resultados indicaram que o espaçamento de 0,80 m favoreceu o desenvolvimento das plantas, principalmente em termos de altura e número de cápsulas, com destaque para o cultivar K3, que apresentou maior produtividade. A análise de correlações fenotípicas demonstrou que o índice de acamamento foi a variável mais relevante na determinação da produtividade do cultivar Trebol, enquanto a altura das plantas foi a principal variável para o cultivar K3. Concluiu-se que o espaçamento entre linhas de 0,80 m é benéfico para a produtividade do gergelim, especialmente para o cultivar K3, e que a densidade de plantas influencia diretamente a arquitetura e a eficiência produtiva das cultivares avaliadas.

PALAVRAS-CHAVE: Sesamum indicum. Densidade populacional. Produtividade.

INTRODUCTION

The production of sesame seeds has increased over the years, keeping up with the growing demand. The sesame seeds market size is estimated to be USD 7.67 billion in 2024, projected to reach USD 8.72 billion by 2029, increasing at an annual rate of 2.60% during the forecast period of 2024-2029 (MORDOR INTELLIGENCE 2024).

The grain cultivated area in Brazil, in 2024, presented a growth of 1.5%, corresponding to 1.18 million hectares more compared to the previous harvest. The largest increase is observed in soybeans, followed by sesame, cotton, sorghum, beans and rice. This demonstrates how the sesame crop has been gaining space as an option for producers, especially in the state of Mato Grosso (CONAB 2024).

Despite the increase, the average productivity of sesame is still considered low when compared to other crops, highlighting the need to develop an innovative technological package for grain production and, especially, for seed production, which is an essential feedstock for crop success.

The spatial arrangement of plants in the field directly interferes with the closing time between rows, phytomass production, plant architecture, disease severity, lodging and crop productivity. This occurs because the arrangement affects intraspecific competition and, consequently, the amount of environmental resources – water, light and nutrients – available to each plant. PRAVALIKA et al. (2024) confirmed that sesame plant spacing significantly influences growth parameters, arguing that spacing of 45 cm × 10 cm resulted in bigger plant height (90.37 cm) and seed yield (1196.67 kg ha^{-1}). For the BRS Seda and Anahi cultivars, produced at different spacings, no interaction was observed for the variables: plant height, stem diameter, height of insertion of the first fruit, number of fruits per plant, number of fruiting branches and productivity (SILVA 2020), suggesting that the choice of spacing depends on the cultivar used.

The use of cultivars without adequate spacing compromises sesame yield, making it essential to evaluate the most appropriate cultivar for each location. This process is essential to identify the ideal genotype of the crop and maximize its productive potential in the region (SILPA et al. 2022).

Even with the importance of this crop, scientific studies that have as their object of research the sowing density and plant population are limited for sesame plants. However, the importance of these studies is justified by some factors, such as introduction of new cultivars on the market; change in the morphophysiological characteristics of the cultivars and the management practices used; and increasing grain productivity to meet market demand, which is a constant challenge. In this context, the objective of this research was to evaluate the influence of different population densities and spacing on the agronomic characteristics of the sesame cultivars Trebol and K3.

MATERIAL AND METHODS

The seed production field was conducted at the experimental unit of EMPAER-Cáceres, from March to July 2022. The soil was corrected and fertilized according to the interpretation of the soil analysis. Sesame seeds of the cultivars Trebol and K3 were used. The experimental design was in randomized blocks, with 12 treatments with three replications, totaling 36 plots. The treatments used consisted of spatial arrangements with varying sowing densities, at spacing of 0.20 and 0.80 m between rows (Table 1). For the number of seeds used per plot in each treatment, a calculation was made based on the germination of seeds of the lot, compensating for 100%

seedling emergence, with an increase of 20%. Each field plot was composed of six rows of 5.0 m in length, and only the four central rows were considered as useful area. A distance of 0.5 m was maintained between each plot, and 1.0 m for the blocks, thus, the cultivars were evaluated separately.

Table 1. Identification of the treatments used to determine the spatial arrangement of the sesame cultivars Trebol and K3, considering the final population.

ultivar	Treatment	*Population	ow_Esp	Cultivar	reatment	opulation	Row_Esp
K3	1	135	0.2	Trebol	7	130	0.2
K3	2	323	0.8	Trebol	8	298	0.8
K3	3	311	0.2	Trebol	9	286	0.2
K3	4	416	0.8	Trebol	10	574	0.8
K3	5	419	0.2	Trebol	11	507	0.2
K3	6	529	0.8	Trebol	12	754	0.8

*Plants per plot counted at the final booth.

Within each plot, six plants were collected from the usable area and the following characteristics were evaluated: plant height, insertion of the first capsule, number of capsules per plant, number of seeds per capsule and estimated productivity. The lodging index was also verified, assigning grades from 1 to 5 (1 – 100% upright plants; 2 – 25% of fallen or leaning plants; 3 – 50% of fallen or leaning plants; 4 – 75% of fallen or leaning plants; 5 – 100% fallen plants).

Manual harvesting was done right after the field evaluation. The plants of the usable plot were tied in bundles, identified and kept in the sun for drying and subsequent processing and laboratory analysis at the Center for Seed Studies and Analysis of the State University of Mato Grosso.

The purity analysis tests, determination of weight of a thousand seeds, adjusted to 5% moisture, germination test and first germination count (BRASIL 2009), and the germination speed index (MAGUIRE 1962) were performed. For the evaluation of data, the statistical program Genes (CRUZ 2013) was used, and the analysis of variance, phenotypic correlations and direct and indirect effects were determined through trail analysis.

RESULTS AND DISCUSSION

The variables evaluated in the field and laboratory showed significant differences, at a level of 5% probability (Table 2) for the cultivar K3 in the lodging index, plant height, capsule insertion height, number of capsules per plant, number of seeds per capsule, yield per plot and weight of one thousand seeds. For the Trebol cultivar, in addition to the differences observed in the K3 cultivar, it was also possible to identify differences in the first germination count.

Table 2. Summary of variance analysis of the variables evaluated in the laboratory and field: (Ia)=lodging index; (Ap)=plant height; (Ins)=capsule insertion height; (Ncap)=number of capsules per plant; (Scap)=number of seeds per capsule; (Prod)=yield per plot; (Ger)=germination; (Pcont)=first germination count; (IVG)=germination speed index and (PMS)=Weight of one thousand seeds of the K3 and Trebol cultivars.

QM –K3 Cultivar											
FV	GL	Ia	Ap	Ins	Ncap	Scap	Prod	Ger	Pcont	IVG	PMS
		(n)	(m)	(m)	(n)	(n)	(g)	(%)	(%)	(a)	(g)
Treatment	5	*0.9	*0.215	0.004	*22402.4	*74.5	*2152935.9	80.8	168.2	37.7	*0.004
Block	2	0.7	0.001	0.002	9323.5	41.5	204830.3	6.2	416.2	57.5	0.0001
Residue	10	0.3	0.015	0.001	3028.9	21.2	136502.7	28.4	122.6	25.2	0.0001
Total	17										
Average	-	1.8	1.1	0.3	131.5	56.6	976.9	96.1	63.8	54.8	0.338
CV%	-	29.5	11.3	12.6	41.8	8.1	37.8	5.5	17.3	9.2	3.4
Min	-	1	0.7	0.3	28	48	205.2	87	53	51.7	0315
Max	-	3	1.4	0.4	226	61	2108.9	100	75	60.8	0.354
QM – Trebol Cultivar											
FV	GL	Ia	Ap	Ins	Ncap	Scap	Prod	Ger	Pcont	IVG	PMS
		(n)	(m)	(m)	(n)	(n)	(g)	(%)	(%)	(a)	(g)
Treatment	5	*2.7	*0.13	0.01	*5793.8	64.7	*455713.4	0.9	*343.4	59.7	*0.0006
Block	2	1.2	0.09	0.01	65.8	150.1	145234.8	0.4	588.22	111.9	0.0001
Residue	10	0.6	0.03	0.01	612.1	67.4	48306.9	1.9	72.22	50.4	0.0001
Total	17										
Average	-	2.5	1.4	0.5	82.5	48.3	646.3	98	35.8	69.0	0.420
CV%	-	32.3	12.9	14.5	30.0	17.0	34.0	1.38	23.8	10.3	2.45
Min	-	1	1.2	0.4	37	41	241.9	98	15	62.6	0.413
Max	-	3	1.7	0.6	162	52	1075.9	99	45	73.5	0.432

(FV)=Source of variation; (CV)=Coefficient of variation; (Min)=Minimum value found; (Max)=Maximum value found; (*) =Significant at 5% probability of error.

According to the average values in Table 3, lodging was higher in plots with 0.80 m spacing between rows for the Trebol cultivar. Plant height was higher in plots with 0.80 m spacing, both for Trebol and K3. The lowest average height occurred at the spacing of 0.20 m. The number of capsules per plant was higher at the spacing of 0.80 m for cultivar K3, with no significant variation for Trebol, except in treatment 8. Production followed the same pattern, with higher values in the spacing of 0.80 m for both the Trebol and K3 cultivars.

Table 3. Analysis of variables averages (Ia)=lodging index; (Ap)=plant height; (Ins)=capsule insertion height; (Ncap)=number of capsules per plant; (Scap)=number of seeds per capsule; (Prod)=yield per plot; (Ger)=germination; (Pcont)=first germination count; (IVG)=germination speed index and (PMS)=Weight of one thousand seeds of the K3 and Trebol cultivars.

Treatme nt	Average –K3 cultivar									
	Ia	Ap	Ins	Ncap	Scap	Prod	Germ	Pcont	IVG	PMS
	(n)	(m)	(m)	(n)	(n)	(g)	(%)	(%)	(a)	(g)
1	1 a	1.03 b	0.32 a	90 b	57 a	243.7 b	87 a	53 a	53.27 a	3.47 a
2	2 a	1.38 a	0.29 a	226 a	61 a	1418.6 a	92 a	60 a	53.33 a	3.51 a
3	1 a	0.74 c	0.37 a	46 b	48 a	244.0 b	100 a	75 a	51.77 a	3.23 b
4	2 a	1.26 a	0.30 a	201 a	57 a	1641.2 a	96 a	67 a	52.33 a	3.38 c
5	1 a	0.83 c	0.37 a	28 b	53 a	205.1 b	100 a	61 a	57.28 a	3.15 d
6	3 a	1.32 a	0.28 a	195 a	60 a	2108.9 a	100 a	66 a	60.88 a	3.54 a
	Average –Trebol cultivar									
7	2 b	1.32 b	0.43 a	88 b	52 a	251.5 b	98 a	40 a	62.61 a	4.32 a
8	3 a	1.56 a	0.53 a	162 a	51 a	995.7 a	99 a	15 b	64.27 a	4.19 b
9	1 b	1.17 b	0.49 a	49 b	41 a	241.9 b	98 a	35 a	71.16 a	4.16 b
10	3 a	1.51 a	0.54 a	82 b	43 a	914.5 a	99 a	42 a	71.22 a	4.20 b
11	1 b	1.23 b	0.54 a	37 b	51 a	398.1 b	99 a	45 a	71.55 a	4.13 b
12	3 a	1.72 a	0.62 a	73 b	49 a	1075.9 a	98 a	36 a	73.49 a	4.20 b

Averages followed by the same lowercase letter in the column for each cultivar do not differ from each other by the Scott and Knott test at 5% probability.

The influence of row spacing on the height of sesame plants is a critical factor in optimizing growth and productivity. Specifically, comparing row spacings of 0.80 m and 0.20 m reveals significant differences in plant height due to variations in plant density and competition for resources. A larger row spacing, such as 0.80 m, usually allows for a greater height of the plant. This is because plants have more access to sunlight, nutrients, and water, reducing competition between them. For example, a study conducted in the Baghdad region concluded that row spacing of 80 cm resulted in the highest yield, which is generally associated with better growing conditions, including increased plant height (ALOBAIDY et al. 2023). These authors also maintain that the results showed different responses of the cultivars according to the spacing between rows.

In contrast, smaller row spacings, such as 0.20 m, can lead to reduced plant height due to competition for light and nutrients (ROY & UMESHA 2023), however, it can also result in compensation due to overall yield per area, which was not observed in this research when associated with smaller spacing.

The yield per area at the 0.80 m spacing was higher than that observed at the 0.20 m spacing for the evaluated cultivars. It is observed that the yield of the K3 cultivar is higher than that of the Trebol cultivar. This observation suggests that the response to spacing may be specific to each cultivar, requiring appropriate agronomic practices to ensure higher yields.

Despite the differences observed in agronomic characteristics, the physiological quality of the seeds was not affected by the production process. Regarding the physical characteristics, variations in weight of one thousand seeds were observed more markedly in the cultivar K3, with weight reduction in populations of 311, 416 and 419 plants per plot (Table 1, Table 3). For the Trebol cultivar, a smaller population has a higher seed weight, with no significant differences when there is an increase in plant population.

In the evaluation of the correlation coefficients (Table 4), the cultivar Trebol has a highly significant correlation between lodging index and plant height and also lodging index and number of capsules per plant; and significant between lodging index and number of capsules per plant. For the K3 cultivar, significant correlations were also observed between lodging index and plant height and between lodging index and number of capsules per plant, highly significant correlations between plant height and number of capsules per plant and between plant height and number of seeds per capsule, in addition to highly significant correlation between number of capsules per plant and number of seeds per capsule (Table 4). These correlations corroborate the results observed in Table 3, in which the agronomic characteristics are more evident in differentiating treatments when the physiological quality characteristics of the seeds are verified.

Based on phenotypic correlations, trail analyses were performed to evaluate the direct and indirect effects of trail coefficient estimates (Tables 5 and 6). The greatest direct effect on production was attributed to the lodging index, with a value of 1.249, with the same trend in total effect, indicating that more productive plants are also more susceptible to lodging. This can also be confirmed by the greater indirect effect of plant height, which has an inverse (negative) relationship with yield, demonstrating that the production of the Trebol cultivar is reduced if there is an increase in plant height, and this indirectly contributes to higher lodging rates, thus proving the effect of this variable on yield (Table 4).

Table 4. Pearson's phenotypic correlation coefficient for the sesame cultivars Trebol and K3, produced by different populations, 2024.

	Ia	Ap	Ins	Ncap	Scap
Trebol					
Ia	1.000				
Ap	0.948**	1.000			
Ins	0.629*	0.660ns	1.000		
Ncap	0.603**	0.519**	-0.097**	1.000	
Scap	-0.005**	0.184**	-0.083*	0.363**	1.000
K3					
	Ia	**Ap**	**Ins**	**Ncap**	**Scap**
Ia	1.000				
Ap	0.852*	1.000			
Ins	-0.859ns	-0.989ns	1.000		
Ncap	0.856*	0.973**	-0.962ns	1.000	
Scap	0.726*	0.927**	-0.917ns	0.817**	1.000

t-test = * significant at 5% probability; ** significant at 1% probability; ns not significant; (Ia)=lodging index; (Ap)=plant height; (Ins)=capsule insertion height; (Ncap)=number of capsules per plant; (Scap)=number of seeds per capsule.

Table 5. Estimation of direct and indirect effects of trail coefficients through genotypic correlations on the trait yield (Prod) as main dependent variable and the traits measured in plants and lodging as independent explanatory variables in the sesame cultivar Trebol.

Traits	Association	CT ED	CT EI	Traits	Association	CT ED	CT EI
Ia	ED on Prod	1.249		Ncap	ED on Prod	-0.062	
	EI via Ap		-0.349		EI via Ia		0.753
	EI via Ins		0.123		EI via Ap		-0.191
	EI via Ncap		-0.037		EI via Ins		-0.019
	Ei via Scap		-0.001		Ei via Scap		0.059
	Total (ED+EI)	0.985			Total (ED+EI)	0.540	
Ap	ED on Prod	-0.368		Scap	ED on Prod	0.164	
	EI via Ia		1.184		EI via Ia		-0.006
	EI via Ins		0.129		EI via Ap		-0.068
	EI via Ncap		-0.032		EI via Ins		-0.016
	Ei via Scap		0.030		Ei via Ncap		-0.022
	Total (ED+EI)	0.943			Total (ED+EI)	0.052	
Ins	ED on Prod	0.195					
	EI via Ia		0.786				
	EI via Ap		-0.243				
	EI via Ncap		0.006				
	Ei via Scap		-0.014				
	Total (ED+EI)	0.731					
	Determination coefficient:			0.999			
	Variable residual effect:			0.004			

CT=Trail coefficient; ED=direct effect; EI=indirect effect; (Ia)=lodging index; (Ap)=plant height; (Ins)=capsule insertion height; (Ncap)=number of capsules per plant; (Scap)=number of seeds per capsule.

The lodging index was the variable with the greatest importance for defining the yield of the Trebol cultivar, both due to direct and indirect effects, mainly via plant height. For the other variables, it is observed that the least relevant for sesame production considering the direct effects is the number of capsules per plant. Another relevant information is related to indirect effects observed for the height of insertion of the first capsule and number of seeds per capsule, since these variables have relationships of greater contribution via the lodging index.

The number of the coefficient of determination shows that all the variation in production is explained by the variables selected to compose the model, and it is relevant to consider the lodging index and plant height to improve the production of the Trebol sesame cultivar.

The decomposition of the total effects observed in the trail analysis for the K3 sesame cultivar indicates that four of the five variables included in the model have a positive relationship with yield, while only the insertion height of the first capsule negatively influences this variable (Table 6).

Table 6. Estimation of direct and indirect effects of the trail coefficients through genotypic correlations on the trait yield (Prod) as main dependent variable and the traits measured in the plants and lodging as independent explanatory variables in the K3 sesame cultivar.

Traits	Association	CT		Traits	Association	CT	
		ED	EI			ED	EI
Ia	ED on Prod	0,516		Ncap	ED on Prod	-4,675	
	EI via Ap		6,791		EI via Ia		0,442
	EI via Ins		0,105		EI via Ap		7,759
	EI via Ncap		-4,003		EI via Ins		0,117
	Ei via Scap		-2,432		Ei via Scap		-2,737
	Total (ED+EI)	0,976			Total (ED+EI)	0,906	
Ap	ED on Prod	7,974		Scap	ED on Prod	-3,349	
	EI via Ia		0,439		EI via Ia		0,375
	EI via Ins		0,121		EI via Ap		7,395
	EI via Ncap		-4,549		EI via Ins		0,112
	EI via Scap		-3,106		Ei via Ncap		-3,820
	Total (ED+EI)	0,879			Total (ED+EI)	0,712	
Ins	ED on Prod	-0,122					
	EI via Ia		-0,443				
	EI via Ap		-7,886				
	EI via Ncap		4,497				
	EI via Scap		3,069				
	Total (ED+EI)	-0,884					
	Determination coefficient:			1,003			
	Variable residual effect:			-			

CT=Trail coefficient; ED=direct effect; EI=indirect effect; (Ia)=lodging index; (Ap)=plant height; (Ins)=capsule insertion height; (Ncap)=number of capsules per plant; (Scap)=number of seeds per capsule.

Plant height was the variable with greatest direct effect on yield (7.974), with taller plants resulting in more productive plants. It is also noteworthy that this variable has very high values when considering its indirect effects via other explanatory variables, such as the number of capsules per plant and number of seeds per capsule, which have a strong positive influence on productivity indirectly due to plant height.

In isolation and by the value of direct effects observed, the capsule insertion height, number of capsules per plant and number of seeds per capsule reduce the production of the K3 cultivar, but their indirect effects partially compensate for their negative influences, especially through their interactions with other variables, such as plant height. Even though it directly causes a reduction in production, the insertion height is the trait that has the least influence within the explanatory model, diverging from the result presented for the Trebol cultivar.

The results of the trail analysis demonstrate that the yield of the K3 cultivar was strongly influenced by plant height, although it is offset by some negative indirect effects via other variables related to the capsules. On the other hand, the Trebol cultivar showed a more balanced influence of variables, with the lodging index exerting a very strong direct and indirect effect on yield of this cultivar, representing valuable information for material selection.

The capsule insertion height exerted a negative influence on both cultivars, however, its impact was more pronounced on the K3 cultivar and may negatively affect production if not properly controlled. Considering these differences, the K3 cultivar may be more suitable for environments that favor the development of taller plants, while the

Trebol cultivar, with multiple variables that contribute in a balanced way to sesame production, seems to be a more stable choice and adapted to more environments.

CONCLUSION

The populations of 323, 529 and 416 plants per plot of the K3 cultivar and 298, 574 and 754 plants per plot of the Trebol cultivar affect the characteristics of the sesame cultivars. For the experimental conditions, the spacing of 0.80 m between rows has evidence of higher productivity.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology and formal analysis, Andréa dos Santos Oliveira; software and validation, Fernando André Silva Santos; investigation, Cláudio das Neves Vieira Bárbara and Pablo Muniz da Cruz; resources and data curation, Tanismare Tatiana de Almeida; writing - preparation of the original draft, Pablo Muniz da Cruz; writing - review and editing, Tanismare Tatiana de Almeida and Andréa dos Santos Oliveira; visualization, Tanismare Tatiana de Almeida and Andréa dos Santos Oliveira; supervision, Cláudio das Neves Vieira Bárbara and Pablo Muniz da Cruz; project management, Tanismare Tatiana de Almeida; fundraising, Tanismare Tatiana de Almeida. All authors have read and agreed with the published version of the manuscript.

FINANCING

This paper was supported by the Fundação de Amparo à Pesquisa do Estado de Mato Grosso.

STATEMENT OF THE INSTITUTIONAL REVIEW BOARD

Not applicable to studies that do not involve humans or animals.

INFORMED CONSENT STATEMENT

Not applicable as this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available upon request.

ACKNOWLEDGEMENT

The authors thank the Fundação de Amparo à Pesquisa do Estado de Mato Grosso – FAPEMAT for the financial support and scholarships granted, allowing the research to be feasible.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest related to the publication of this article.

EDITORS

Information to be filled in by the editorial team.

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