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# Agronomic performance of chia under different spatial arrangements

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## ABSTRACT

The nutritional benefits and functional potential of chia seeds have been highlighted in the literature. However, few studies address the planting system of the species, especially its spatial arrangement. Thus, this study proposes to evaluate chia cultivation under different spatial arrangements, aiming at its agronomic performance. The experimental design was randomized in blocks in a 3×2 factorial scheme, with three inter-row spacings (0.30, 0.45, and 0.60 m), two plant densities per linear meter (7.5 and 15 plants $m^{-1}$), and four replications. Plant height, stem diameter, leaf area index, dry matter, chlorophyll index, leaf nitrogen content, panicle size, harvest index, and yield were evaluated. The evaluated spatial arrangements did not influence plant height, stem diameter, dry matter, leaf nitrogen content, panicle size, and harvest index. However, the spatial arrangement with the narrowest spacing and the highest population density was more suitable for obtaining a higher leaf area index and yield, with values of 5.96 and 2,507.44 kg $ha^{-1}$, respectively. Therefore, a higher leaf area index and chia seed yield are obtained with an inter-row of 0.30 m and a population density of 15 plants $m^{-1}$, that is, 500 thousand plants $ha^{-1}$.

**Keywords:** Harvest index, Lamiaceae*,* Agronomic management*, Salvia hispanica* L.

## Desempenho agronômico da chia sob diferentes arranjos espaciais

## RESUMO

Na literatura são destacados os benefícios nutricionais e o potencial funcional das sementes de chia, entretanto, ainda são poucos os trabalhos que abordam o sistema de plantio, em especial o arranjo espacial. Dessa forma, propôs-se no presente trabalho avaliar o cultivo da chia em diferentes arranjos espaciais, visando o seu desempenho agronômico. O delineamento experimental foi em blocos ao acaso, em esquema fatorial 3x2, sendo três espaçamentos entre linhas (0,30, 0,45 e 0,60 m) e duas densidades de plantas por metro linear (7,5 e 15 plantas $m^{-1}$) com quatro repetições. Foram avaliadas altura de planta, diâmetro de caule, índice de área foliar, matéria seca, índice de clorofila, teor de nitrogênio foliar, tamanho da panícula, índice de colheita e produtividade. Os arranjos espaciais avaliados não influenciam a altura de plantas, diâmetro do caule, matéria seca, teor de nitrogênio foliar, tamanho da panícula e índice de colheita, sendo que o arranjo espacial composto pelo espaçamento mais estreito e a maior densidade populacional mostrou-se mais adequado para obtenção de índice de área foliar e produtividade mais elevados, nos valores de 5,96 e 2.507,44 kg $ha^{-1}$, respectivamente. Concluiu-se que para obter maior índice de área foliar e produtividade de grãos de chia, a semeadura deve ser feita no espaçamento entre linhas de 0,30 m com densidade populacional de 15 plantas $m^{-1}$, ou seja, 500 mil plantas $ha^{-1}$.

**Palavras-chave**: Índice de colheita, Lamiaceae*, M*anejo agronômico*, Salvia hispanica* L.

## 1. Introduction

Chia (*Salvia hispanica* L.) is an herbaceous plant belonging to the family Lamiaceae, as well as the aromatic herbs basil, mint, oregano, and thyme, used in cooking (Ixtaina et al., 2011; Capitani et al., 2012). Its seeds have beneficial health properties, such as high content of protein, antioxidants, and dietary fiber (Ixtaina et al., 2011). The species is also rich in minerals, such as phosphorus, potassium, calcium, magnesium, iron, zinc, manganese, and copper (Coates, 2012). Thus, it has been increasingly cultivated due to increased popularity (Muñoz et al., 2012).

In Brazil, chia finds the best conditions for its development in October and November in western Paraná and the northwestern Rio Grande do Sul, reaching a yield of 800 kg ha$^{-1}$ in May (Migliavacca et al., 2014), and 1,254.80 kg ha$^{-1}$ in southern Minas Gerais, also in May (Vilela et al., 2016). The recommended inter-row spacing is 0.70 m for Argentina (Busilacchi et al., 2013) and between 0.40 to 0.60 m with a density of 12 plants m$^{-2}$ in Nicaragua (Miranda, 2012). Ayerza and Coates (2006) mentioned that 6 to 8 kg ha-1 is used in Argentina and Mexico for sowing, with an inter-row distance of 0.7 to 0.8 m and a distance between plants of 4 to 6 cm in the row, reaching a population of 20–30 plants per linear meter.

In contrast, mint, a plant of the same family as chia, is grown in Brazil with an inter-row spacing of 0.40 m and a density of 3.3 plants per meter to reach 84,000 plants ha$^{-1}$ (Azevedo and Moura, 2010). According to Assis et al. (2014), the most suitable plant arrangement for better use of light, water, and nutrients is the one that provides a more uniform plant distribution in the sowing row, reflecting in yield. The average yield found in the original producing regions of the crop (southern Mexico and northern Guatemala) is 500 to 600 kg ha$^{-1}$, but some producers have obtained yields of up to 1,200 kg ha$^{-1}$ (Coates, 2011). Biomass production is favored due to the high light availability, which stimulates photoassimilate production (Vilela et al., 2016).

The literature has studies emphasizing the nutritional benefits and the functional potential of chia seeds, but few of these studies have addressed the planting system. The difficulty found regarding the lack of information on agronomic management directly affects the increase in its planted area, being necessary more studies to prove the preliminary results obtained on chia cultivation, approaching several subjects related to crop implantation, mainly regarding its spatial arrangement.

Thus, this study proposes to evaluate chia cultivation under different spatial arrangements, analyzing its agronomic performance.

## 2. Material and Methods

The experiment was conducted in the field at the Federal Institute of Education, Science, and Technology of Southern Minas Gerais – IFSULDEMINAS, campus of Muzambinho, MG, Brazil, in the winter of the 2017/18 agricultural season. The soil of the experimental area was classified as a typic dystrophic Red-Yellow Latosol (LVAd) (Santos et al., 2018), located at an altitude of 1,100 meters. The region fits into the Cwb climate type, according to Köppen (1948), that is, a high-altitude tropical climate, characterized by rainy summers and more or less dry winters. According to Aparecido and Souza (2018), the average temperature and average annual rainfall are 18.2 °C and 1,605 mm, respectively.

The experimental design consisted of randomized blocks in a 3×2 factorial scheme, consisting of three inter-row spacings (0.30, 0.45, and 0.60 m) and two plant densities per linear meter (7.5 and 15 plants m$^{-1}$), with four replications, totaling 24 experimental plots of 4 m in length and 2.4 m in width, with a useful area of 4.8 m$^2$ in the three inter-row spacings. Soil sampling was carried out in the 0 to 20 cm layer of the experimental site to characterize its fertility. The soil analysis interpretation was based on Boletim Técnico 100 (Raij et al., 1996), using the recommendations for water mint and spearmint, as they belong to the same family as chia.

The experiment was conducted from March to July, with planting and sowing fertilization carried out on March 31, 2017, with the formula 08–28–16 at 187.5 kg ha$^{-1}$ and single superphosphate ($P_2O_5$) at 397.06 kg ha$^{-1}$. Topdressing fertilization was performed using 30 kg ha$^{-1}$ of nitrogen (N) 30 days after sowing (DAS) at 142.85 kg ha$^{-1}$ of ammonium sulfate as a source. Phytosanitary management was carried out only to control ants. In addition, two weeds were carried out to control weeds until the closure of the inter-rows.

The following evaluations were carried out at flowering (68 DAS) on 10 plants in the useful area of each experimental plot: plant height (PH, cm), measured with a graduated ruler from the collar to the inflorescence insertion; stem diameter (SD, mm), measured using a digital caliper on the 2nd internode of the main stem; panicle size (PS, cm), determined with a graduated ruler from the inflorescence insertion on the main stem to the panicle apex; leaf area index (LAI), based on leaf area (LA), measured with a Cid Bio-Science CI-202 device, with the total sum being divided by the soil area occupied by the plants; total dry matter (DM, g), measured by drying the shoot and root system in an air-circulation oven at 65±5 °C for 72 hours.

The total chlorophyll index (CI), evaluated using the ClorofiLOG device, with readings on the leaves of the middle third of the plant; and leaf nitrogen content (NLeaf, g kg$^{-1}$), following the methodology proposed by Malavolta e al., (1997), with the collection of the leaves sampled for

CI, subsequently dried in an oven, ground in a Willey mill, and sent for chemical analysis of N in the Laboratory of Soil and Plant Tissue Analysis at IFSULDEMINAS, campus of Muzambinho, MG, Brazil.

Harvesting was performed manually in the entire useful area of the plots when the plants reached 80% of the leaves with a dark color, dry or dead, as recommended by Miranda (2012), at 107 DAS. Subsequently, the 10 plants already used in the phytometric evaluations at the beginning of flowering were separated and their panicles were threshed and sieved to obtain the average grain mass per plant, which was extrapolated to kg ha$^{-1}$ as a function of the plant population in each experimental plot according to the spatial arrangement. The harvest index was also determined by the formula HI = (grain yield/biological yield, which is the value of the total dry matter of the plants) × 100. The collected data were submitted for analysis of variance and compared with each other using the Scott-Knott test at a 5% probability level in the SISVAR® program (Ferreira, 2011).

## 3. Results and Discussion

Plant height, stem diameter, LAI and dry matter did not differ regarding the isolated factors, inter-row spacing, and plant density in the row. Moreover, no interaction was observed between these factors (Table 1), except for LAI at the inter-row spacing of 0.30 m, which had a higher value with 15 plants m$^{-1}$ than 7.5 plants m$^{-1}$ (Table 2). Vilela et al. (2016) also conducted a study in Muzambinho, MG, Brazil, with chia plants and obtained a height of 23.1 cm and a stem diameter of 2.2 mm in the winter season, that is, much lower than the values found in the present study (Table 1). According to Lemos Júnior and Lemos (2012), chia plants grow up to 100 cm in height, reaching up to 200 cm in the summer in Brazil (Migliavacca et al., 2014).

The reduction in the inter-row spacing between rows may lead to changes in the amount of dry matter accumulated by plants, closing the inter-row area (Scott and Aldrich, 1975), leaf area, and LAI (Pires et al., 1998). However, these changes were not verified in the present study for LAI and dry matter (Table 1), but for the interaction between the smaller inter-row spacing and higher plant density, which resulted in higher LAI of chia (Table 2). The high coefficient of variation value for LAI (Table 2) occurred because the smaller effect on the population is due to the ability to compensate for the use of space between plants, such as in soybean (Peixoto et al., 2000).

**Table 1.** Plant height (PH, cm), stem diameter (SD, mm), leaf area index (LAI), and total dry matter (DM, g) of chia under different inter-row spacings and number of plants per meter. Muzambinho, MG, Brazil, winter of the 2017/18 season.

| Treatment | PH (cm) | SD (mm) | LAI | DM (g) |
|---|---|---|---|---|
| Inter-row spacing (m) | | | | |
| 0.30 | 85.42 a | 5.28 a | 4.35 a | 23.48 a |
| 0.45 | 88.14 a | 5.67 a | 4.00 a | 36.89 a |
| 0.60 | 83.69 a | 5.34 a | 2.31 a | 22.40 a |
| Number of plants per meter | | | | |
| 7,5 | 87.84 a | 5.52 a | 2.77 a | 28.04 a |
| 15 | 83.67 a | 5.34 a | 4.34 a | 27.12 a |
| CV (%) | 12.42 | 11.54 | 51.58 | 68.36 |

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at the 5% probability level.

**Table 2.** Leaf area index (LAI) as a function of the interaction between inter-row spacing and the number of plants per meter. Muzambinho, MG, Brazil, winter of the 2017/18 season.

| Leaf area index (LAI) | | | |
|---|---|---|---|
| Number of plants per meter | Inter-row spacing (m) | | |
| | 0.3 | 0.45 | 0.6 |
| 7,5 | 2.74 bA | 3,59 aA | 1,98 aA |
| 15 | 5.96 aA | 4,42 aA | 2,64 aA |
| CV (%) | 51.58 | | |

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other by the Scott-Knott test at the 5% probability level.

CI and NLeaf did not differ regarding the isolated factors, inter-row spacing and plant density in the row, and no interaction was observed between factors for NLeaf (Table 3). Digital chlorophyll meters are used as additional tools for managing nitrogen fertilization, as it is positively correlated with leaf N content in the plant (Neves et al., 2005).

In contrast, CI showed an interaction between inter-row spacing and the number of plants per meter. The inter-row spacing of 0.60 m with 7.5 plants $m^{-1}$ had a CI higher than the density of 15 plants $m^{-1}$ (Table 4). The lowest plant density in the largest inter-row spacing allowed for less intraspecific competition, leading to a higher solar radiation capture since the chlorophyll molecule, a key pigment of chloroplasts, is responsible for this capture, resulting in higher photosynthetic activity (Taiz and Zeiger, 2013).

Panicle size and HI showed no statistical difference for inter-row spacings and plant densities in the row when evaluated separately (Table 5), as well as for the interaction between factors. Moreover, the smaller the inter-row spacing, the higher the yield per area when the treatments are analyzed separately. In addition, regarding the number of plants in the row, the yield was higher with 15 plants $m^{-1}$ (Table 5), as population density influences production gain or loss per area.

An interaction was observed for the factor yield between the factors inter-row spacing and the number of plants per meter, and the density of 15 plants $m^{-1}$ at the inter-row spacing of 0.3 m presented the highest average, reaching 2,507.44 kg $ha^{-1}$ (Table 6), as also observed for LAI since an increase in the production rate can be obtained by increasing the leaf area index (Larcher, 2006), which reflects the leaf density because there is higher availability of photosynthetically active surface.

**Tabela 3.** Total chlorophyll index (CI) and leaf nitrogen content (NLeaf, g $kg^{-1}$) of chia under different inter-row spacings and number of plants per meter. Muzambinho, MG, Brazil, winter of the 2017/18 season.

| Treatment | CI | NLeaf (g $kg^{-1}$) |
|---|---|---|
| Inter-row spacing (m) | | |
| 0.30 | 39.36 a | 23.01 a |
| 0.45 | 40.63 a | 22.76 a |
| 0.60 | 38.39 a | 21.04 a |
| Number of plants per meter | | |
| 7.5 | 40.18 a | 22.48 a |
| 15 | 38.75 a | 22.07 a |
| CV (%) | 6.15 | 10.32 |

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at the 5% probability level.

**Tabela 4.** Total chlorophyll index (CI) as a function of the interaction between inter-row spacing and the number of plants per meter. Muzambinho, MG, Brazil, winter of the 2017/18 season.

| Total chlorophyll index (CI) | | | |
|---|---|---|---|
| Number of plants per meter | Inter-row spacing (m) | | |
| | 0.3 | 0.45 | 0.6 |
| 7.5 | 38.90 aA | 41.30 aA | 40.33 aA |
| 15 | 39.83 aA | 39.95 aA | 36.46 bA |
| CV (%) | | 6.15 | |

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other by the Scott-Knott test at the 5% probability level.

**Tabela 5.** Panicle size (PS, cm), harvest index (HI) and yield (YIELD, kg $ha^{-1}$) of chia under different inter-row spacings and number of plants per meter. Muzambinho, MG, Brazil, winter of the 2017/18 season

| Treatment | PS (cm) | IC | YIELD (kg $ha^{-1}$) |
|---|---|---|---|
| Inter-row spacing (m) | | | |
| 0.30 | 18.89 a | 5.05 a | 1.834.45 a |
| 0.45 | 18.65 a | 5.22 a | 1.266.67 b |
| 0.60 | 19.78 a | 4.79 a | 741.80 c |
| Number of plants per meter | | | |
| 7.5 | 19.07 a | 5.35 a | 953.56 b |
| 15 | 19.14 a | 4.69 a | 1.608.38 a |
| CV (%) | 13.09 | 35.94 | 27.53 |

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at the 5% probability level.

**Tabela 6.** Yield (YIELD, kg $ha^{-1}$) as a function of the interaction between inter-row spacing and the number of plants per meter. Muzambinho, MG, Brazil, winter of the 2017/18 season.

| Yield (kg $ha^{-1}$) | | | |
|---|---|---|---|
| Number of plants per meter | Inter-row spacing (m) | | |
| | 0.3 | 0.45 | 0.6 |
| 7.5 | 1.161.46 bA | 993.75 bA | 705.47 aA |
| 15 | 2.507.44 aA | 1.539.58 aB | 778.13 aC |
| CV (%) | | 27.53 | |

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other by the Scott-Knott test at the 5% probability level.

This yield value was relatively high compared to the yield values obtained by Vilela et al. (2016) at the same cultivation site, which reached 1,254.80 kg $ha^{-1}$ in the summer season, which should be the most productive (Migliavacca et al., 2014). Bochicchio et al. (2015) studied the densities of 4, 8, 25, and 125 plants $m^{-2}$ in Italy and observed that the growth and production of chia were higher at high sowing density.

Most of the evaluated agronomic characteristics were not influenced by the spatial arrangement, either by the different spacings or by the different densities. The spatial arrangement consisting of the inter-row spacing of 0.3 m and population density of 15 plants $m^{-1}$ proved to be more suitable for obtaining higher yield and a higher population density. According to Pereira et al. (2007), the association of management practices, reduction in spacing, and increase in plant population result in a significant increase in yield.

## 4. Conclusions

Higher values of leaf area index and grain yield of chia are obtained with sowing at the inter-row spacing of 0.30 m with a population density of 15 plants $m^{-1}$, that is, 500 thousand plants $ha^{-1}$.

## Authors' Contribution

João Paulo Teodoro Maia: investigation, writing of the original draft, review, and formal analysis. Wellington Garcia da Silva: investigation, writing, review, and formal analysis. Ariana Vieira Silva: conceptualization, investigation, writing, review, editing, formal analysis, and supervision. Otavio Duarte Giunti: conceptualization, writing, review, editing, and formal analysis. Raul Henrique Sartori: writing, review, formal analysis, and supervision.

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