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# Nitrogen management in golden and brown flax crops

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**Abstract:** The cultivation of oleaginous flax, winter cultivation, intended for grain production in the state of Rio Grande do Sul. A few decades ago, the primary purpose of cultivation was to meet the demand of industries for the production of varnishes and paints. Currently, there is a growing interest in the culture for human consumption of grains in natura as food ingredients and oil consumption, as it is considered noble due to the high content of omega 3. For many decades, investment in research for flax cultivation was low, generating a gap in the literature for crop management, such as the adjustment of cover nitrogen recommendation for flax. The objective of this study was to evaluate the agronomic performance of oleaginous flax, brown and golden varieties, in subtropical and tropical climates in Brazil to adjust N management, based on cover nitrogen fertilization. The experiments were conducted in three cultivation sites in the state of Rio Grande do Sul and one site in Minas Gerais. The experiments were conducted on the following soils: Arenic Dystrophic Red-Yellow Argisol (Santa Maria-RS), Dystrophic Red Latosol for the municipality (Palmeira das Missões-RS), Ferric Alumino Red Latosol (Frederico Westphalen-RS), Yellow Red Argisol (Viçosa-MG). The treatments consisted of a bifactorial (2 x 6), with two varieties of oleaginous flax, (brown and golden), and six doses of nitrogen (0, 30, 60, 90, 120, and 150 kg ha$^{-1}$. The dose of 81.08 kg ha$^{-1}$ is enough for the adequate agronomic performance of flax brown and golden varieties crops in subtropical and tropical climate environments with regular water availability, based on the maximum technical efficiency for the use of cover N.

**Keywords:** *Linum usitatissimum* L., maximum technical efficiency for nitrogen fertilization, rational use of fertilizers, vegetable oil-producing plants; omega 3 in grains.

**Abbreviations:** SM_Santa Maria – RS; FW_Frederico Westphalen – RS; PM – Palmeira das Missões – RS; VÇ_Viçosa – RS; CV_coefficient of variation; PH_plant height, NCP_number of capsules per plant, TGW_Thousand grain weight, GY_grain yield; VF_Variation Factor; DF_Degrees of freedom.

## Introduction

Introducing new crops within a cultivation system and providing alternative income to farmers can contribute to greater sustainability of the production system since the practice of crop rotation is considered a cultural management used to reduce the incidence of diseases, pests, and weeds. Flax is an autogamous plant of the Linaceae family, genus *Linum* L., and species *Linum usitatissimum* L., grown in the winter period in Brazil, and can be used in crop rotation systems with the cultivation of wheat, which is the main agricultural winter crop in the south of the country. The cultivation of flax is divided between the use of cultivars for the extraction of plant fiber and cultivars for the extraction of oil and its byproducts (oleaginous flax). However, the world cultivation of oleaginous flax is 12 times higher than fibrous flax (Kiryluk and Kostecka, 2020).

The grains of the flax culture are known as flaxseed and an increase in consumption in human food is observed due to the nutritional qualities of the oil produced. The culture presented a large area of cultivation in the 60s due to industry demands for the quality of its oil. Among the benefits, the oil has rapid solidification after exposure to air, being used alone or combined with other oils on wood and as an important constituent of oil-based paints (Borugadda, and Goud, 2012).

In Brazil, the demand for flaxseed grains and oil has been increasing for the purpose of use in human food. Flaxseed grains are rich in omega-3, digestible proteins, and lignans, being one of the richest sources of α-linolenic acid oil and lignans, providing high-quality protein and soluble fiber, also having the potential as a source of phenolic compounds. Thus, it is considered a functional food ingredient due to its rich content in α-linolenic acid (ALA), lignans, and fibers, providing a wide variety of benefits to human and animal health (Singh et al., 2011). Currently, the production of flax grains in Brazil is 12.9 thousand tons, and almost all of the production originates from the state of Rio Grande do Sul, a small value compared to the current world production, which was 3.06 million tons in 2019 (Faostat, 2020).

This low production of oleaginous flax in relation to world grain production is associated with a limited investment in research to

**Table 1.** Analysis of variance and significance of the mean square of the sources of variation, experimental coefficient of variation (CV), mean comparison for flax cultivars brown and gold regarding plant height (PH), number of capsules per plant (NCP), Thousand grain weight (TGW), and grain yield (GY) in the state of Rio Grande do Sul (Santa Maria, Frederico Westphalen, and Palmeira das Missões) and the state of Minas Gerais (Viçosa), in 2021 Santa Maria – RS, 2024.

| | | Mean Square | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| VF | DF | Santa Maria - RS | | | | Frederico Westphalen - RS | | | |
| | | PH | NCP | TGW | GY | PH | NCP | TGW | GY |
| Cultivars | 1 | 661.19$^{*}$ | 17.4$^{ns}$ | 0.52$^{ns}$ | 19505.34$^{ns}$ | 444.39$^{*}$ | 0.021$^{ns}$ | 0.02$^{ns}$ | 72568.29$^{ns}$ |
| Block | 3 | 103.79$^{ns}$ | 5.24$^{ns}$ | 0.21$^{ns}$ | 22208.99$^{ns}$ | 20.74$^{*}$ | 2.21$^{ns}$ | 0.03$^{ns}$ | 21313.53$^{ns}$ |
| Residue A | 3 | 52.79 | 3.25 | 0.22 | 28632.73 | 1.49 | 1.08 | 0.05 | 38900.81 |
| Dose N | 5 | 500.18$^{*}$ | 54.27$^{*}$ | 2.39$^{*}$ | 159459.08$^{*}$ | 65.43$^{*}$ | 9.07$^{*}$ | 0.05$^{*}$ | 62770.43$^{*}$ |
| Cult. x D. | 5 | 12.15$^{ns}$ | 3.83$^{ns}$ | 0.23$^{ns}$ | 4788.37$^{ns}$ | 8.22$^{ns}$ | 2.09$^{ns}$ | 0.03$^{ns}$ | 10332.13$^{ns}$ |
| Residue B | 30 | 11.98 | 3.03 | 0.44 | 11029.98 | 7.36 | 3.15 | 0.01 | 7613.95 |
| C.V.1 | | 9.12 | 21.65 | 10.02 | 26.39 | 1.85 | 12.7 | 4.31 | 17.33 |
| C.V.2 | | 4.34 | 20.91 | 14.08 | 16.38 | 4.12 | 21.71 | 2.29 | 7.67 |
| Mean | | 79.67 | 8.32 | 4.69 | 641.3 | 65.88 | 8.17 | 5 | 1137.9 |
| Brown | | 83.39a | | | | 68.92a | | | |
| Golden | | 75.96b | | | | 62.84b | | | |

| | | Mean Square | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| VF | DF | Palmeira das Missões - RS | | | | Viçosa - MG | | | |
| | | PH | NCP | TGW | GY | PH | NCP | TGW | GY |
| Cultivars | 1 | 35.19$^{ns}$ | 6.14$^{ns}$ | 0.37$^{*}$ | 85285.47$^{ns}$ | 1695.84$^{ns}$ | 137.98$^{ns}$ | 0.1$^{ns}$ | 85134.63$^{ns}$ |
| Block | 3 | 20.83$^{ns}$ | 3.04$^{ns}$ | 0.01$^{ns}$ | 155070.09$^{ns}$ | 224.13$^{ns}$ | 8.65$^{ns}$ | 0.03$^{ns}$ | 121614.03$^{*}$ |
| Residue A | 3 | 24.16 | 0.77$^{ns}$ | 0.01 | 61848.79 | 534.33 | 105.6 | 0.04 | 12495.33 |
| Dose N | 5 | 36.37$^{*}$ | 4.28$^{ns}$ | 0.12$^{*}$ | 58463.71$^{*}$ | 70.67$^{ns}$ | 18.83$^{ns}$ | 0.01$^{ns}$ | 100303.43$^{*}$ |
| Cult. x D. | 5 | 13.6$^{ns}$ | 2.18$^{ns}$ | 0.01$^{ns}$ | 36304.33$^{ns}$ | 37.36$^{ns}$ | 7.04$^{ns}$ | 0.01$^{ns}$ | 79559.36$^{ns}$ |
| Residue B | 30 | 11.31 | 2.03$^{ns}$ | 0.01 | 21903.19 | 93.52 | 15.32 | 0.01 | 33650.83 |
| C.V.1 | | 8.09 | 16.41 | 1.25 | 30.28 | 25.77 | 60.44 | 4.14 | 9.11 |
| C.V.2 | | 5.54 | 26.68 | 2.05 | 18.02 | 10.78 | 23.02 | 2.02 | 14.95 |
| Mean | | 60.75 | 5.35 | 5.13 | 821.28 | 89.71 | 17.00 | 5.04 | 1226.83 |
| Brown | | | | 5.22a | | | | | |
| Golden | | | | 5.05b | | | | | |

VF: Variation Factor; DF: Degrees of freedom; $^{*}$: Significant effect by the F test at 5% probability and ns: Non-significant. Means followed by the same letter in the column do not differ at 5% probability by Scott Knott test.

promote its cultivation in Brazil and the investment for the development of new cultivars. Adjustments are also necessary in crop management and search for new cultivation areas close to major consumer centers in Brazil, such as the expansion of crops to tropical regions where wheat is grown.

The flax culture has plasticity for sowing density and has temperature and water availability as limiting factors to its development (Casa et al., 1999). Flax responds positively to adequate cover nitrogen supply, as reported in studies conducted in Brazil (Osmari et al., 2019), Greece (Dordas, 2010), China (Liu et al., 2020; Zhang, 2021), and Russia (Prakhova and Turina, 2021). However, the response to N occurs up to a certain limit. Excessive doses can favor lodging, which, in addition to reducing grain yield, makes mechanical harvesting difficult. Combined with this, excessive rates of N can contribute to a higher emission of $N_2O$ of agricultural soils, an important greenhouse gas (Chai et al., 2019), and the eutrophication of rivers and lakes. N fertilization can influence the concentration of N in different parts of the flax plant, affecting the response to environmental conditions (Dorbas, 2011) and providing an increase in the crop cycle (Kakabouki et al., 2021).

Evaluating the agronomic performance, based on the adjustment of the cover N dose for the state of Rio Grande do Sul and the high altitude tropical region in Minas Gerais where wheat is cultivated, is essential to enhance the efficiency of nitrogen use in flax crops and favor the cultivation of oleaginous flax by family farming in Brazil. In this sense, this study aimed to evaluate the agronomic performance of oleaginous flax in subtropical and tropical climates in Brazil, based on cover nitrogen fertilization.

## Results and Discussion

It can be inferred that the experiments have adequate experimental accuracy for the four environments (SM, FW, PM, VÇ) (Table 1). The interaction Varieties x Nitrogen dose had no significance for PH, NCP, TGW, and GY in any of the environments, only PH in FW for dose and variety. This fact may be associated with the morphological characteristics of the oleaginous flax varieties that are close since there was only significant effect of the flax variety factor for the nitrogen doses factor for the PH character in SM and FW, and TGW showed significance of the same factor only for the PM environment, while the other sites and characters did not present significant effects. This similar response between the two varieties of oleaginous flax was also observed in a study conducted in the state of Santa Catarina, where the authors identified a similar effect between both varieties and the influence of their response to the growing environment when characterizing the growth and grain productivity (Stanck et al., 2017).

The brown variety was superior to the golden variety for PH in SM based on the Tukey test, with averages of 83.39 cm, while the golden variety presented PH of 75.96 cm and in FW with 68.92 cm compared to with 62.84 cm, values close to 82.6 cm observed in Curitibanos-SC (Stanck et al., 2017). The brown variety presented values of 5.22 g for the TGW character, with superiority to the golden cultivar, with TGW of 5.05 g, mean values higher than that observed by Stanck et al. (2017).

The effects of the characters PH, NCP, TGW, and GY were significant for N dose in the SM environment (Figure 2). The adjustment occurred with a quadratic regression for PH and GY and linear for NCP and TGW. There were similar PH and GY responses, i.e., when the crop response to increased nitrogen increases, there is an initial growth that is accompanied by greater plant height, which begins to be reduced by higher doses of N, and may have a strong influence of plant lodging, which have a lower translocation of photoassimilates and reduction in plant height as an effect (Santos et al., 2013).

PCN presented a linear increasing response, indicating that the greater availability of N favors the emergence of capsules per plant. TGW presented a decreasing linear response, which can be explained by the environmental conditions where there was

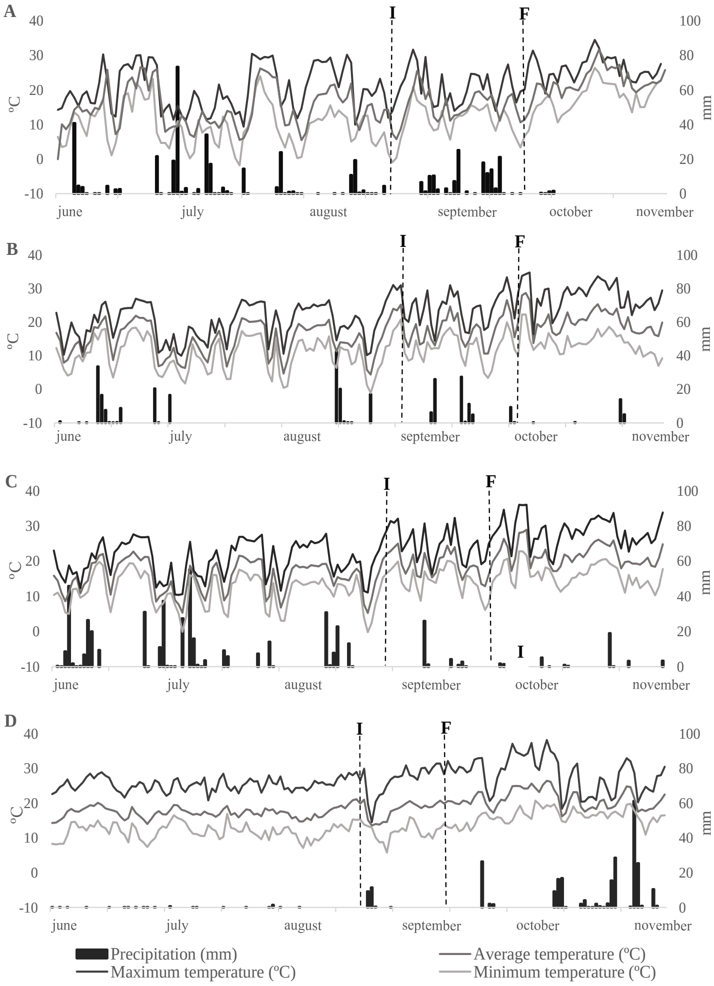

**Figure 1.** Daily averages of maximum, minimum, and average temperatures and precipitation in Santa Maria (A), Palmeira das Missões (B), and Frederico Westphalen (C), in the state of Rio Grande do Sul, and Viçosa (D), in the state of Minas Gerais, in the period from June 1st to November 9th of 2020. I: Beginning of flowering. F: End of flowering.

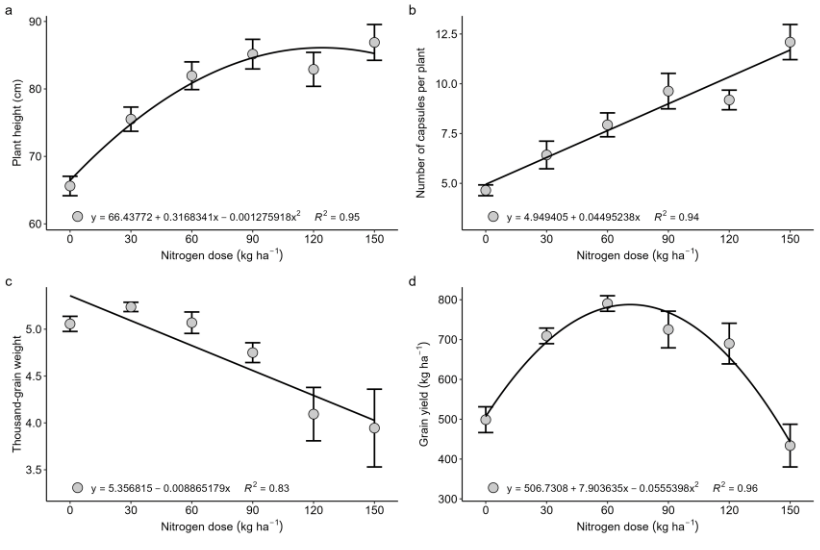

**Figure 2.** Plant height (a), number of capsules per plant (b), mass of one thousand grains (c), and grain yield (d) of flaxseed varieties as a function of nitrogen dose (kg ha$^{-1}$), in 2021, Santa Maria - RS, 2024.

no precipitation in the second fortnight of October in Santa Maria, until the end of the crop cycle in November, influencing the translocation of photoassimilates for the complete filling of grain reserves. In FW, the dose of N was significant for the characters PH, NCP, TGW, and GY (Figure 3) and the characters PH and GY showed a similar response to the experiment in SM. The response was cubic for NCP and quadratic for TGW and may be associated with a better distribution of precipitation in the grain-filling period, with precipitation in early November. However, a reduction in TGW was observed with high doses of N, with the plant showing incomplete filling of the grains. The NCP character, which was significant in the N doses for the SM and FW

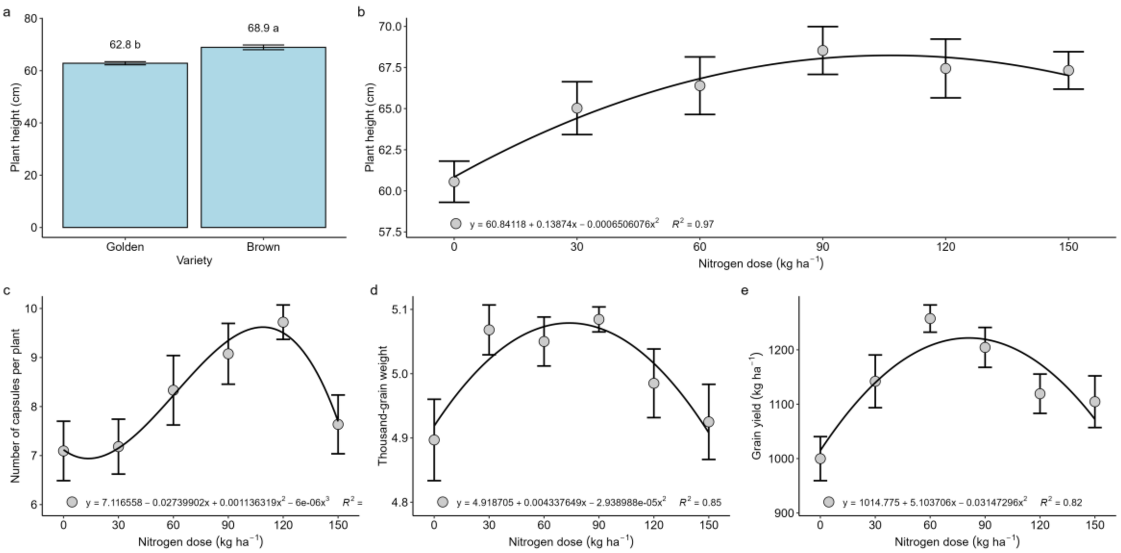

**Figure 3.** Plant height (a), number of capsules per plant (b), mass of one thousand grains (c), and grain yield (d) of flaxseed varieties as a function of nitrogen dose (kg $ha^{-1}$), in 2021 Frederico Westphalen - RS, Santa Maria, 2024.

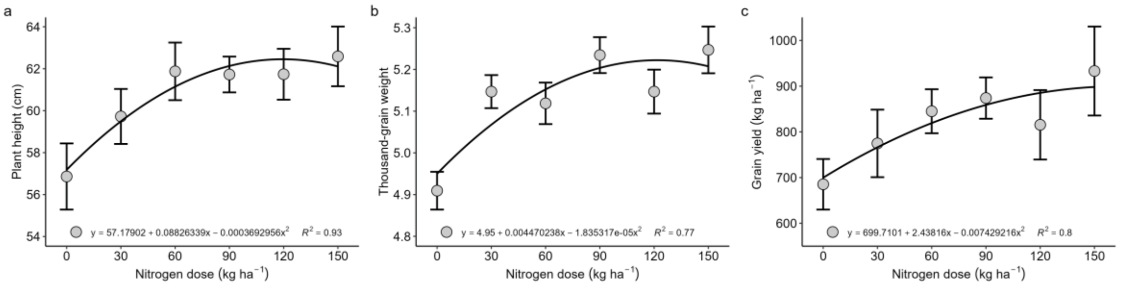

**Figure 4.** Plant height (a), number of capsules per plant (b), mass of one thousand grains (c), and grain yield (d) of flaxseed varieties as a function of nitrogen dose (kg $ha^{-1}$), in 2021 Palmeira das Missões - RS, Santa Maria, 2024.

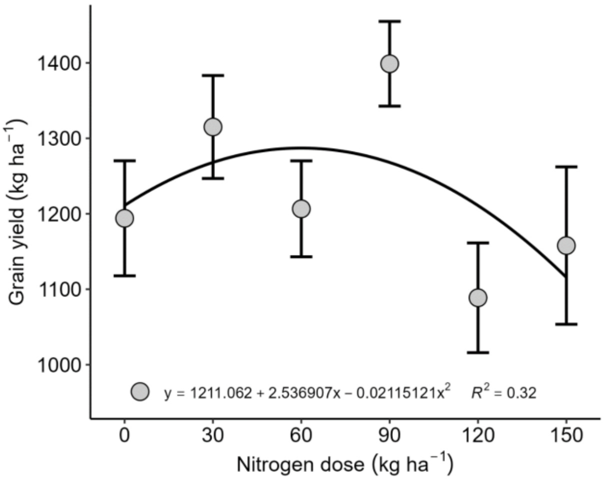

**Figure 5.** Grain yield of flaxseed varieties as a function of nitrogen dose (kg $ha^{-1}$), in Viçosa - MG, Santa Maria, 2024.

experiments, was also highlighted in studies of linear relationships, where they indicate a positive relationship with GY (Cargnelutti Filho et al., 2016; Siddiqui et al., 2016).

In the third study environment in the state of Rio Grande do Sul, the characters PH, TGW, and GY were significant for N dose in PM (Figure 4). There was a significant effect of N doses for PH and GY, observed in the other two environments in the state of Rio Grande do Sul. This response indicates a trend towards these characteristics and shows that high doses of N in the oleaginous flax crop provide problems associated with plant lodging, even in an agricultural year with low precipitation towards the end of the crop cycle. For TGW, the quadratic regression was close to that of the FW environment, which can be justified by environmental conditions such as temperature and water availability, and distribution close to both environments (Figure 1). Quadratic regression adjustments were also observed for the characters PH, NCP, TGW, and GY in an experiment with the golden variety of the oleaginous flax in the north of the state of Paraná (Santos et al., 2013), reinforcing the results obtained in this research.

For the tropical environment in VÇ, the N dose factor was significant only for GY (Figure 5), where the adjusted regression was also quadratic. In this environment, precipitation was not a limiting factor due to the provision of supplementary irrigation when necessary. For air temperature, this environment differed from those in the state of RS since the average temperature was

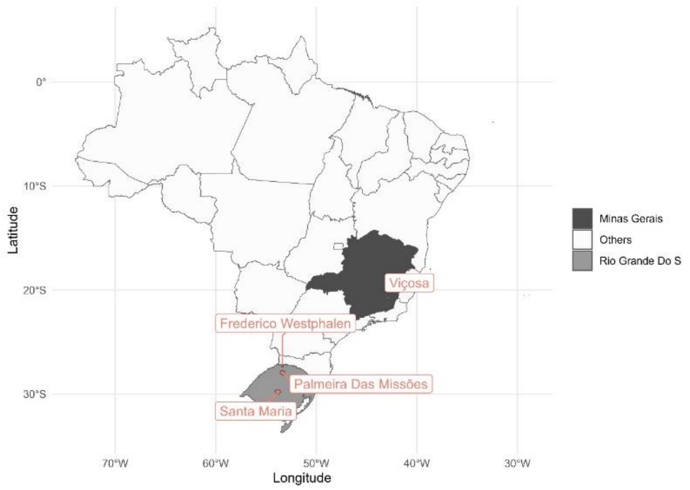

**Figure 6.** Geographical representation of the four locations where oilseed flax trials were conducted in the states of Rio Grande do Sul and Minas Gerais in Brazil, Santa Maria, 2024.

higher than in the other three environments (Figure 1). It was also observed that low temperatures, close to zero degrees, did not occur, as is common in southern Brazil, indicating that the oleaginous flax crop has the capacity to adapt to another Brazilian climate besides the subtropical, where the largest area of flax cultivation in Brazil is cultivated. This is proven by the GY averages obtained, with the highest average being close to 1,400 kg ha$^{-1}$. These results indicate that further research can be conducted in the state of MG since the crop is more of a winter alternative for crop rotation systems, with the product harvested closer to the major consumer centers of the country. In addition to positive responses to the dose of cover N flax crops in subtropical and tropical humid environments observed in the present study, the scientific literature indicates that the crop also presents an increasing response to increased N supply in a temperate climate environment in Greece (Dorbas, 2010).

This response to the increase in productive potential in different climates highlights the great potential for adaptation of flax and the importance of nitrogen supply to the crop. In a study with the nutritional index of N, Dorbas (2011) found that environmental conditions influence N absorption, referring to the importance of adjusting certain management in more than one environment.

Similar responses occurred for the maximum technical efficiency (MTE) in SM, FW, and VÇ for the variable GY. For PM, the response was well above what was observed in other environments, which may have been influenced by the marked water deficit for the vegetative period during experimentation (Figure 1). Therefore, this environment will be disregarded for the result discussion.

The MTE for SM was 71.15 kg ha$^{-1}$ of N and 81.08 kg ha$^{-1}$ of N for the FW environment. For VÇ, the maximum technical efficiency was 59.97 kg ha$^{-1}$ of N, with a value close to the management of N in subtropical environments. It is noteworthy that a management close to 80 kg of N per ha meets the demand of these varieties of oleaginous flax for these regions of Brazil. In studies developed in China, Liu et al. (2020) observed that the culture responds to a dose of 150 kg ha$^{-1}$ of N, values higher than the response of the brown and golden varieties in Brazil. Zhang, (2021), also in China, indicated that this fertilization for flax cultivation is excessive, and the dose of 90 kg ha$^{-1}$ of N should be adopted to increase crop efficiency. The results of this study are close to the present study in Brazil, which conditioned an efficient nitrogen response in values between 60 to 80 kg ha$^{-1}$ of N.

Other studies in the literature indicate responses to doses lower than those indicated in the present study, as in Russia, with a recommendation of 30 kg ha$^{-1}$ of N (Prakhova and Turina, 2021), in Greece with 40 kg ha$^{-1}$ of N (Dorbas et al., 2010), and in Croatia for fibrous flax at a dose of 30 kg ha$^{-1}$ of N (Brunsek, et al., 2022). These different responses show the importance of adjusting nitrogen fertilization in each cultivating environment since factors such as climate, soil type, and soil chemistry, with emphasis on the organic matter present, can influence the recommendation of this management. The sources of nitrogen fertilization also influence grain productivity in oleaginous flax crops (Emam, 2019; Kakabouki et al., 2021).

## Materials and methods

### *Locations of study*

The research was conducted in a network of trials in four locations: three of them in a subtropical climate in the state of Rio Grande do Sul, in Santa Maria (SM), with an altitude of 95 m (29°43'23"S and 53°43'15"W), Frederico Westphalen (FW), with an altitude of 493 m (27°39'56"S and 53°42'94"W), Palmeira das Missões (PM), with an altitude of 639 m (27° 53'56"S and 53°18'50"W), and a location of tropical climate in the state of Minas Gerais, in Viçosa, 20°45'14"S and 42°52'55"W, at an altitude of 648 m (Figure 6). Locations in the state of Rio Grande do Sul traditionally cultivate flax and the state of Minas Gerais have great potential for flax cultivation. The soils of the different flax-growing regions are classified as Arenic Dystrophic Red-Yellow Argisol for the municipality of Santa Maria-RS, Dystrophic Red Latosol for the municipality of Palmeira das Missões-RS, Ferric Alumino Red Latosol for the municipality of Frederico Westphalen-RS, and Yellow Red Argisol for the municipality of Viçosa-MG (Embrapa, 2018). The climate, according to the Koppen classification, is classified as Cfa for the municipalities of the state of RS and Cwa for the municipality of MG (Alvares et al., 2013). Meteorological data for the characterization of each site were obtained from automatic meteorological stations located near the experiments (Figure 1).

### *Conduction of study and experimental design*

The treatments consisted of a bifactorial (2 x 6), with two varieties of oleaginous flax (brown and golden), and six doses of nitrogen (0, 30, 60, 90, 120, and 150 kg ha$^{-1}$) in randomized blocks with four replicates. The randomization of treatments followed the structure of subdivided plots, in which flax cultivars were randomized in the main plots and nitrogen doses in the subplots. The experimental units were plots of 2.5 m long by 2.0 m wide, equivalent to an area of 5 m$^2$. Each plot was composed of ten rows with spacing between rows of 20 cm, considering six central lines per plot as useful area.

The data were submitted to the analysis of variance. When significant, the cultivar factor was analyzed by the Tukey multiple comparison test and linear regression analysis was performed for the nitrogen doses factor, where polynomial models were adjusted using the statistical software R (R Core Team, 2020). The maximum technical efficiency (MTE) was calculated for grain yield, when the adjusted polynomial model was quadratic, adopting a 5% probability of error in all statistical analyses.

### *Plant materials*

The study lasted 162 days, between June and November 2020. Flax sowing was carried out manually in June for the four sites, using 80 kg of viable seeds per hectare. The base fertilization was carried out according to the result of the soil analysis of each environment by applying the formula NPK 5-20-20, adequate to the production expectation of 2 ton ha$^{-1}$, according to the manual of fertilizing and liming for the flax culture. The application of nitrogen doses was carried out in a unique way, at the beginning of the branching of the crop.

For the variables analyzed, 20 oleaginous flax plants were collected at the end of the crop cycle. The collection was carried out in a sequence of five plants in four random points of the useful area of the subplot to evaluate plant height (PH in cm); number of capsules per plant (NCP); mass of one thousand grains (TGW in g); and grain yield (GY in kg ha$^{-1}$).

## Conclusions

Plant height was greater for the brown variety compared to the golden variety in half of the environments, while the superiority of the brown variety was in only ¼ of the environments for the mass of one thousand grains. For the number of capsules and mass of one thousand grains, the response to nitrogen fertilization did not differ statistically between varieties.

The dose of 80 kg ha$^{-1}$ is enough for the adequate agronomic performance of flax crops in subtropical and tropical climate environments with regular water availability, based on the maximum technical efficiency for the use of cover N.

The cultivation of oleaginous flax in the winter period is indicated for subtropical (central and northwest region of RS) and tropical (southwest of MG) climate environments in Brazil.

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