Morphology of linseed cultivars in contrasting sowing seasons

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Abstract – The objective of this work was to evaluate the morphological responses of different genotypes of linseed and to identify the ideal time for sowing seeds in the northwest of the state of Rio Grande do Sul. The design used was randomized blocks organized in a factorial scheme: linseed cultivars (IJUI001, IJUI002, and IJUI003) × sowing dates April 15th (I), April 30th (II), May 15th (III), May 30th (IV), June 15th (V), June 30th (VI), and July 15th (VII) with treatments arranged in six replications. Sowing times influence linseed grain yield. Sowings between April 30th and June 15th showed 61% higher grain yield. Linear trends change according to sowing times, such as stem diameter, mass and number of capsules, number and weight of grains per plant, which together define the productivity of linseed grains per unit area.

Index terms: *Linum usitatissimum*; Interrelations; Meteorological variables.

Morfologia de cultivares de linhaça em épocas de semeadura contrastantes

Resumo – O objetivo deste trabalho foi avaliar as respostas morfológicas de diferentes genótipos de linhaça e identificar a época ideal para a semeadura no noroeste do Rio Grande do Sul. O delineamento utilizado foi blocos casualizados e organizado em esquema fatorial: cultivares de linhaça (IJUI001, IJUI002 e IJUI003) × épocas de semeadura 15 de abril (I), 30 de abril (II), 15 de maio (III), 30 de maio (IV), 15 de junho (V), 30 de junho (VI) e 15 de julho (VII) com os tratamentos dispostos em seis repetições. As épocas de semeadura influenciam o rendimento de grãos da linhaça. As semeaduras entre 30 de abril e 15 de junho apresentaram maiores rendimentos de grãos. As tendências lineares mudam de acordo com as épocas de semeadura, como diâmetro da haste, massa e número de cápsulas, número e peso de grãos por planta, que juntos definem a produtividade de grãos de linhaça por unidade de área.

Termos de indexação: *Linum usitatissimum;* Inter-relações; variáveis meteorológicas.

Introduction

Linseed (*Linum usitatissimum*) is an important oilseed and fibrous plant that belongs to the family *Linaceae* and genus *Linum*. Among oilseeds, it is the most abundant source of alpha-linolenic acid, a substance with antioxidant function (ANDRUSZCZAK et al., 2015; GOYAL et al., 2014), and lignin (KAJLA et al., 2015), which has a beneficial effect on disease prevention and human health.

Linseed represents an alternative for cultivation systems due to its adaptability to poor soils and its high economic value compared with the high quality of the oil in the grains, which has been increasingly appreciated by consumers and food and cosmetics industries (ZANETTI et al., 2013). The crop exhibits good growth in low temperature environments, such as linseed fiber cultivars that grow best in wet, cool climates. Its cultivation is generally located in regions of low altitudes; however, it can be cultivated at 770 meters of altitude, either in dryland or irrigated areas with a water requirement of 450 to 750mm distributed uniformly during the cultivation cycle (STANCK et al., 2017). The lowest basal temperature for plant growth and development is 4.8°C, and temperatures between −4°C to −7°C in the germination period can inhibit the emergence due to freezing the seeds (CASA et al., 1999), with light frost formation (−1°C) being able to severely damage flowers and immature capsules. The most severe frost damage usually occurs when crops are sown in the autumn season, since their reproductive periods coincide with more favorable times for these events to occur.

Grain yield is a trait controlled by a large number of genes strongly influenced by the environment. The sowing time is one of the most influential managements on crop grain yield, with the ideal time being described as a relevant condition for germination, establishment, and other growth periods (MIRZAIE et al., 2020).

The sowing time of linseed according to Moura (2008), Soares et al. (2009) and Marques (2008), occurs between the months of April to June and the harvest, which varies according to the sowing, in the months of November, December, and January. Oliveira et al. (2012) also describe that the sowing occurs until the month of June and the harvest in the month of October or in the beginning of November. Sowing carried out in the right period is extremely important, as is the uniformity of seedling emergence and the development of the root system. Furthermore, it makes it possible to overlap the critical periods for the production of oil and its components with the time of the growing season,

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when more environmental resources are available (CEH et al., 2020).

Growth and development parameters are fundamental for controlling productivity, and by understanding the relationship between these parameters and environmental factors, it is possible to identify the ability of the crop to adapt and the effectiveness of its growth. In this context, this work aims to evaluate the morphological responses of different genotypes and to identify the ideal time for sowing linseed in the northwest of the state of Rio Grande do Sul.

Materials and Methods

The field experiment was carried out in the experimental area of Instituto Regional de Desenvolvimento Rural da Universidade Regional do Noroeste do Estado do Rio Grande do Sul, located in the municipality of Augusto Pestana in Rio Grande do Sul, at coordinates 28° 26' 30" S and 54° 00' 58" W, altitude of 301 meters. The soil is classified as Typical Dystroferric Red Latosol and the climate of the region is *Cfa* type according to the Köppen climate characterization.

The design used was randomized blocks and organized in a factorial scheme: linseed cultivars – IJUI001, IJUI002, and IJUI003 × sowing dates – April 15th (I) (177 days), April 30th (II) (167 days), May 15th (III) (154 days), May 30th (IV) (162 days), June 15th (V) (141 days), June 30th (VI) (143 days), and July 15th (VII) (160 days), with treatments arranged in six replications. The plots consisted of 17 sowing lines spaced at 0.18 meters, totaling an area of 15 square meters. The useful area was formed by two central sowing lines, to minimize the border effects and to evaluate the characteristics of the plants. A density of 150 seeds per linear meter was used, with base fertilization with 200kg ha^{-1} of NPK 05-20-20 and 60kg ha^{-1} of urea (45% N) 30 days after sowing, carried out preventively to minimize the abiotic effects on the results of the experiment. The variables measured were height of insertion of the first capsule (HIFC, cm), plant height (PH, cm), cycle (CYCLE, days), stem diameter (SD, mm), number of stem branches (NSB, unit), number of productive branches (NPB, unit), number of capsule (NCAP, unit), mass of capsule (MCAP, grams), number of capsules that formed grain (NCFG, unit), number of capsules that formed no grain (NCNFG, unit), number of grains per plant (NGPP, unit), weight of grains per capsule (WGPC, grams), weight of grains per plant (WGPP, grams), thousand grain weight (TGW, grams), grain yield (GY, kilos), plant stand (STAND, unit). The climatological attributes evaluated were minimum temperature (Tmin, °C), medium temperature (Tmed, °C), maximum temperature (Tmax, °C), temperature amplitude (AMP, °C), and precipitation (mm).

The data obtained were subjected to the assumptions of the statistical model, normality and homogeneity of residual variances and model additivity. Subsequently, descriptive analysis and analysis of variance at 5% probability were performed using the F-test, testing the interaction between cultivars × sowing dates. The variables that showed significant interaction were broken down to simple effects at 5% probability. Linear correlation was performed to understand the trend of association between variables with significance based on the t-test at 5% probability.

Results and Discussion

In this experiment, the mean minimum air temperature (Tmin) ranged from 7.7°C to 16.2°C, in which the lowest temperature was recorded in July. The mean maximum temperature (Tmax) varied between 19.06°C and 31.3°C, where the highest temperature occurred in December. In May a slight formation of frost was observed, without severe damage to the development of the culture. However, in the months of June, July, and August, the intense consecutive frost damaged mainly the genotypes in the flowering period, sown in seasons April 15th (I), May 01st (II), May 15th (III), and June 01th (IV) mainly. Subsequently, in September, hail caused the loss of reproductive organs. The main frost damage occurred during the crop's reproductive period. Casa et al. (1999) report basal temperatures of 4.8°C from the beginning of flowering to harvest.

The accumulated rainfall during linseed cultivation at different sowing dates was 1136mm, with the highest volume recorded in the second half of July (>320mm). However, the months of August and September were marked by low rainfall.

Early sowing of linseed developed at lower temperatures was prone to greater damage due to low air temperatures; however, as sowing was delayed, development occurred at higher temperatures, due to the variation environment in each sowing season. The temperature range was similar during all seasons, above 10°C and below 15°C. The largest accumulation of precipitation was identified in the seasons of April 15th (I) and April 30th (II), close to 1000mm, whereas the lowest precipitation occurred in the season of July 15th (VII), less than 500mm. Earlier sowings tend to result in longer development cycles. Early sowing can bring some gaps, such as low temperature and occurrence of pests and diseases, whereas delay in sowing can delay the growth of linseed production due to physiological maturity and lack of carbohydrates (MIRZAIE et al., 2020).

The early sowing of linseed promoted a tendency of plants with longer development cycles for both genotypes, as in season I, which presented cultivars with more than 170 days of cycle. This occurs due to the low temperatures during vegetative development, which reduces the accumulation of degrees day. For Mirzaie et al. (2020), early sowing is characterized by low temperatures and the occurrence of pests and diseases during development, which may also explain the lower results obtained for grain yield on April 15th (I) season.

Frost damage occurs when linseed is sown early, such as in autumn (STANCK et al., 2017). The results of low grain yield on April 15th (I) may have been a consequence of the intense frosts that occurred in the month of July, period in which the linseed was in flowering, and in late August, period of flowering and grain filling, thus, the cultivars presented more than one period of flowering due to the death of reproductive organs by frost, leading to the expenditure of energy to form new flowerings, which may limit the grain yield. Added to all these events, the low rainfall also influenced the agronomic performance of linseed, since the rains were a limiting element from the second half of August until October 25th, a period that added up to only 2.60mm.

The delay in sowing can reduce the growth of linseed production, since it shifts the seed and capsule ripening periods to higher environmental temperatures (GALLARDO et al., 2014; MIRZAIE et al., 2020). This corroborates the results of this research, in which the last two sowings showed the lowest grain yields for both genotypes. The highest yields were observed in sowings from April 30th to June 15th, with superiority for the April 30th season (II). The main reason for the high linseed yields for these seasons seems to be the favorable temperatures in May and June, which leads to faster plant growth, eventually stronger plants, and higher grain yields.

The agronomic performance of the genotypes at different sowing times is reflected in the net value of return to producers, since the greatest economic results are observed in the seasons April 30th (II), May 15th (III), May 30th (IV), and June 15th (V), with a minimum of 70% higher than the other sowing dates. Note that the production costs (R$1,000.00) are the same regardless of the sowing time.

The analysis of variance (Table 1) revealed a significant interaction between linseed cultivars × sowing dates for the variables height of insertion of the first capsule (HIFC), plant height (PH), mass of capsule (MCP) and weight of grains per plant (WGPP), number of capsules that formed grains (NCFG), number of grains per plant (NGPP), and plant stand (STAND) indicating mainly that the genotypes do not have constant performance in the sowing times. It also showed the absence of interaction for number of capsules (NCAP), development cycle (CYCLE), stem diameter (SD), thousand grain weight (TGW), number of stem (NSB), and productive branches (NPB) and grain yield (GY). On the other hand, the crop cycle (CYCLE), stem diameter (SD), number of capsules (NCAP), number stem branches (NSB), number of productive branches (NPB), and grain yield (GY) exhibited significance as a function of sowing seasons. The thousand grain weight (TGW) revealed

Table 1. Summary of analysis of variance for three linseed cultivars in seven sowing seasons in Northwest of the State of Rio Grande do Sul, Brazil

Tabela 1. Resumo da análise de variância para três cultivares de linhaça em sete épocas de semeadura no Noroeste do Estado do Rio Grande do Sul, Brasil

FV	Pr>Fc							
	DF	HIFC [1]	PH	CYCLE	SD	MCAP	WGPP	TGW
Blocks	5	0.628	0.088	0.000*	0.664	0.018	0.0567	0.153
Seasons	6	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.364
Cultivars	2	0.000*	0.000*	0.992	0.593	0.045*	0.180	0.035*
Seasons x Cultivars	12	0.009*	0.000*	1	0.806	0.004*	0.000*	0.313
Residue	100							
Total	125							
CV (%)		5.60	5.56	2.55	15.11	29.53	31.48	37.76

FV								
	DF	NCAP	NCFG	NGPP	NSB	NPB	GY	STAND
Blocks	5	0.007*	0.027	0.06	0.023*	0.034*	0.149	0.756
Seasons	6	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
Cultivars	2	0.8	0.029*	0.067	0.056	0.62	0.135	0.000*
Seasons x Cultivars	12	0.664	0.043*	0.020*	0.957	0.698	0.275	0.002*
Residue	100							
Total	125							
CV (%)		28.69	27.25	29.57	15.67	35.91	33.43	14.73

[1] HIFC: Height of insertion of the first capsule (cm); PH: Plant height (cm); CYCLE: Cycle (days); SD: Steam diameter (mm); MCAP: Mass of capsule (grams); WGPC: Weight of grain per capsule (grams); TGW: Thousand grain weight (grams); NCAP: Number of capsules (unit); NGPP: Number of grains per plant (unit); NSB: Number of stem branches (unit); NPB: Number of productive branches (unit); GY: Grain yield (kg ha^{-1}) and STAND: Plant stand (unit). *Significant at 5% probability.

*[1] HIFC: Altura de inserção da primeira cápsula (cm); PH: Altura da planta (cm); CICLO: Ciclo (dias); SD: Diâmetro do vapor (mm); MCAP: Massa da cápsula (gramas); WGPC: Peso do grão por cápsula (gramas); TGW: Peso de mil grãos (gramas); NCAP: Número de cápsulas (unidade); NGPP: Número de grãos por planta (unidade); NSB: Número de ramos do caule (unidade); NPB: Número de ramos produtivos (unidade); RG: Produção de grãos (kg ha^{-1}) e STAND: Estande de plantas (unidade). *Significativo a 5% de probabilidade.*

significance due to the cultivar variation factor.

The coefficients of variation were considered low for height of insertion of the first capsule, plant height, cycle, stem diameter, number of stem branches, and plant stand. However, the yield components, such as mass of capsule, weight of grains per capsule, thousand grain weight, number of capsules per plant, number of capsules that formed grains, number of grains per plant, number of productive branches, and grain yield, showed a tendency to exhibit high coefficients of variation possibly due to the great influence of the environment on the expression of these characteristics.

The breakdown of the simple effects between sowing dates × linseed cultivars (Table 2) showed superior

Table 2. Breakdown of the simple interaction effects of comparison of means for three linseed cultivars in seven sowing seasons in Northwest of the State of Rio Grande do Sul, Brazil

Tabela 2. Decomposição dos efeitos de interação simples da comparação de médias para três cultivares de linhaça em sete épocas de semeadura no Noroeste do Estado do Rio Grande do Sul, Brasil

Seasons	Cultivars			Seasons	Cultivars		
	IJUI001	IJUI002	IJUI003		IJUI001	IJUI002	IJUI003
	Variables				Variables		
	HIFC [1]				NCFG		
I	64.78 bcA	62.33 cA	56.43 cdB	I	17.38 aA	11.23 aB	12.65 abB
II	76.00 aA	69.90 bB	65.06 bB	II	13.55 abA	11.81 aA	13.83 aA
III	80.60 aA	76.70 aAB	72.23 aB	III	10.88 bcA	9.45 abA	12.00 abA
IV	68.56 bAB	73.10 abA	68.06 abB	IV	7.61 cdA	9.75 abA	8.81 bcA
V	58.83 cdA	57.66 cdA	56.90 cA	V	10.48 bcA	10.16 abA	8.28 bcA
VI	53.88 dA	55.60 dA	50.73 dA	VI	5.32 dA	4.23 cA	7.06 cA
VII	56.96 dA	55.36 dAB	50.93 cdB	VII	7.93 cdA	5.65 bcA	7.06 cA
	PH				NGPP		
I	102.56 aA	87.14 abB	85.23 aB	I	100.51 aA	62.88 abB	61.13 abB
II	90.93 bA	86.73 abAB	84.60 aB	II	84.93 aA	71.86 aA	86.75 aA
III	91.33 bA	87.53 aAB	81.96 abB	III	70.11 abA	61.21 abA	79.35 aA
IV	79.00 cA	79.86 bA	76.66 bA	IV	48.18 bcA	64.36 abA	57.96 abcA
V	69.03 dA	66.10 cA	65.50 cA	V	69.65 abA	70.88 aA	58.20 abcA
VI	62.06 dA	61.40 cAB	55.83 dB	VI	30.75 cA	22.78 cA	29.25 cA
VII	63.53 dA	62.83 cAB	57.43 dB	VII	51.08 bcA	37.48 bcA	45.68 bcA
	MCAP				STAND		
I	0.96 aA	0.60 abB	0.54 bcB	I	2162037 dA	1791667 dA	2592593 dA
II	0.76 abA	0.74 aA	0.81 aA	II	6513889 bA	5138889 bcB	6740741 abA
III	0.57 bcA	0.48 bcA	0.59 abA	III	6800926 bA	5625000 bB	5282407 cB
IV	0.35 cdA	0.46 bcA	0.42 bcdA	IV	8694444 aA	7069444 aB	7402778 abB
V	0.46 cdA	0.46 bcA	0.37 bcdA	V	6805555 bAB	6328704 abB	7759259 aA
VI	0.23 dA	0.18 dA	0.21 dA	VI	5576389 bA	5486111 bA	6152778 bcA
VII	0.37 cdA	0.29 cdA	0.34 cdA	VII	3944444 cA	3921296 cA	4875000 cA
	WGPP						
I	0.55 aA	0.27 abcB	0.26 bcB				
II	0.48 abA	0.41 aA	0.45 aA				
III	0.38 abcA	0.36 abA	0.41 abA				
IV	0.24 cdeA	0.35 abA	0.31 abcA				
V	0.33 bcdA	0.35 abA	0.27 bcA				
VI	0.12 eA	0.14 cA	0.15 cA				
VII	0.20 deA	0.19 bcA	0.20 cA				

[1] Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically at 5% probability by Tukey's tests.1 HIFC: Height of insertion of the first capsule (cm); PH: Plant height (cm); MCAP: Mass of capsule (grams); WGPP: Weight of grains per plant (grams); NCFG: Number of capsules that formed grains (unit); NGPP: Number of grains per plant (unit); STAND: Plant stand (unit). Sowing seasons: I (April 15th); II (April 30th); III (May 15th); IV (May 30th); V (June 15th); VI (June 30th) and VII (July 15th).

[1] Médias seguidas da mesma letra minúscula na coluna e maiúscula na linha não diferem estatisticamente a 5% de probabilidade pelos testes de Tukey.1 *HIFC: Altura de inserção da primeira cápsula (cm); PH: Altura da planta (cm); MCAP: Massa da cápsula (gramas); WGPP: Peso de grãos por planta (gramas); NCFG: Número de cápsulas que formaram grãos (unidade); NGPP: Número de grãos por planta (unidade); ESTANDE: Estande de plantas (unidade). Épocas de semeadura: I (15 de abril); II (30 de abril); III (15 de maio); IV (30 de maio); V (15 de junho); VI (30 de junho) e VII (15 de julho).*

results in the IJUI001 genotype for the height of insertion of the first capsule (HIFC) on April 30th (II) and May 15th (III) as a function of the occurrence of precipitation and adequate temperatures during the growing season. However, the IJUI002 and IJUI003 genotypes showed higher insertion heights of the first capsule on May 15th (III) seasons, influenced by favorable temperatures during cultivation in these seasons.

For Stanck et al. (2017), high daily temperatures damage leaf photosynthesis components, limiting carbon dioxide assimilation and plant height compared to environments that have temperatures close to ideal. Earlier sowings promote a dominant positive effect on plant height during the vegetative phase (SAGHAYESH et al., 2014).

Plant height was reduced in late sowings. Thus, sowing between the periods of April 15th and April 30th lead to better plant development, due to the occurrence of precipitation and temperatures favorable to the crop. The delay in sowing meant the occurrence of low temperatures, associated with water stress, reducing plant height.

Likewise, the measurement of the mass of capsule (MCAP) and weight of grains per plant (WGPP) showed a reduction with the delay in sowing, due to the same conditions that interfered with plant height. However, both mass of capsule and weight of grains per plant did not differ between cultivars for all seasons, except for the first sowing season, where IJUI001 was higher. The same occurred for the number of capsules that formed grains and number of grains per plant, in which the genotypes did not differ, except in the period April 15th (I) with superiority for IJUI001. In general, yield components, as well as linseed productivity, are related to the plant growth period and environmental conditions, the longer the growth period and the better the edaphoclimatic conditions, the greater the agronomic performance (MIRZAIE et al., 2020). Yield components, as well as linseed productivity, are related to the plant's growth period and environmental conditions, the longer the growth period and the better the edaphoclimatic conditions, the greater the agronomic performance (MIRZAIE et al., 2020). Linseed yield components tend to decrease with sowing delay, such as the number of capsules that formed the grain (NCFG) and the number of grains per plant (NGPP). These variables were affected by delayed sowing, where high temperatures were observed, reaching close to 37.5°C in the reproductive stage, and the most affected times were June 30th (VI) and July 15th (VII). Late sowing causes linseed plants to coincide with grain filling under high temperatures, which results in a high rate of plant respiration, reduced storage of photoassimilates and reduced grain yield (SAGHAYESH et al., 2014).

The cultivars IJUI001 and IJUI002 exhibited the highest plant stand (STAND) on May 30th (IV) and IJUI003 on June 15th (V), due to the rainfall that occurred shortly after sowing and the optimal temperatures for emergence and culture establishment. April 15th (I) was the one that showed the lowest plant stand due to the period without rainfall of up to 18 days after sowing, a factor that made a large number of seeds unviable. The seasons June 30th (VI) and July 15th (VII) showed reduced plant stands as a result of heavy rainfall after sowing. This may explain the low productivity of these seasons, since the number of plants per unit area is a direct component of linseed grain productivity. In general, the seasons May 30th (IV) and June 15th (V) show a high stand of plants due to the ideal rainfall soon after sowing, promoting rapid germination and emergence of seedlings, in addition to reducing exposure of seeds to pests and diseases.

The results of the comparisons of means (Table 3) also showed a tendency of reduction of the yield

Table 3. Test of comparison of means for different variables in seven sowing seasons of the linseed crop in Northwest of the State of Rio Grande do Sul, Brazil

Tabela 3. Teste de comparação de médias para diferentes variáveis em sete épocas de semeadura da linhaça no Noroeste do estado do Rio Grande do Sul, Brasil

Seasons	Variables						
	NSB [1]	NPB	GY	NCAP	TGW	SD	CYCLE
I	5.17 a	22.66 a	791.97 b	20.55 a	4.97 a	2.53 b	173 a
II	5.34 a	13.45 b	2675.47 a	20.20 a	5.60 a	2.56 ab	168 b
III	4.05 b	8.46 c	2242.15 a	12.35 b	6.17 a	2.87 a	157 d
IV	4.13 b	7.80 cd	2364.78 a	9.66 bc	5.63 a	2.20 c	143 f
V	4.11 b	8.25 c	2227.59 a	10.34 bc	4.86 a	2.01 cd	134 g
VI	3.59 b	4.17 d	801.14 b	5.22 d	5.41 a	1.33 e	163 c
VII	4.13 b	6.02 cd	861.75 b	8.02 cd	4.79 a	1.77 d	148 e

[1] Means followed by the same lowercase letter in the column do not differ statistically at 5% probability by Tukey's tests. [1]NSB: Number of stem branches (unit); NPB: Number of productive branches (unit); GY: Grain yield (kg ha^{-1}); NCAP: Number of capsules (unit); TGW: Thousand grain weight (grams); SD: Stem diameter (mm); CYCLE: Cycle (days). Sowing seasons: I (April 15th); II (April 30th); III (May 15th); IV (May 30th); V (June 15th); VI (June 30th) and VII (July 15th).

[1] Médias seguidas pela mesma letra minúscula na coluna não diferem estatisticamente a 5% de probabilidade pelos testes de Tukey. [1]NSB: Número de ramos do caule (unidade); NPB: Número de ramos produtivos (unidade); RG: Produção de grãos (kg ha^{-1}); NCAP: Número de cápsulas (unidade); TGW: Peso de mil grãos (gramas); SD: Diâmetro da haste (mm); CICLO: Ciclo (dias). Épocas de semeadura: I (15 de abril); II (30 de abril); III (15 de maio); IV (30 de maio); V (15 de junho); VI (30 de junho) e VII (15 de julho).

components as the sowing is delayed, whereas a balanced trend was observed for the thousand grain weight. April 15th (I) showed high results for yield components; however, the low grain yield might have been caused by several frosts during the most sensitive periods of crop development, such as flowering and grain filling, which promoted the formation of several blooms and, consequently, the lengthening of the cycle and grain filling under high temperatures. In addition, the reduced plant stands also added to the limiting factors of productivity. Thus, the cycle may have been influenced by the frosts and the ability to form new linseed blooms, as due to the tendency to reduce the cycle as sowing is delayed, but this changes from June 30th (VI), which possibly caused the extension due to the need to produce a new flowering due to the death of reproductive organs by frost.

The highest grain yields are expressed in the seasons April 30th (II), May 15th (III), May 30th (IV), and June 15th (V). These times coincided with ideal rainfall for seed germination and seedling emergence. Frosts were observed in the flowering periods of April 30th (II), May 15th and throughout June (III), and in August, but by the capacity of resilience, production recovery occurred, unlike the April 15th (I) period, which was in the period of grain formation, thus, showing a trend of greater losses in grain yield the more advanced the plant development period is during frost formation. Also, the average maximum temperatures of the production months of these seasons were 22.23°C, 21.2°C, 19.06°C, 24.6°C, 24.5°C, and 28.3°C in the months of May to October, respectively. The seasons of June 30th (VI) and July 15th (VII) presented the longest period of grain filling in the months of November with an average maximum of 30.2°C and December with temperatures of 31.1°C, thus the seasons April 30th (II), May 15th (III), May 30th (IV), and June 15th (V) showed most plant development at more favorable maximum temperatures, promoting greater physiological efficiency of the plants. Gallardo et al. (2014) and Choi et al. (2012) showed similar results, in which the highest grain yield of linseed occurred in early sowing.

The results of the mean comparisons between the genotypes (Table 4) showed differences only for thousand grain weight (TGW), so that the IJUI002 genotype expressed the highest results and the IJUI001 cultivar did not differ from the best. Grain yield, number of stem branches, number of productive branches did not differ significantly between cultivars. The thousand grain weight was reported to be 4.79 to 5.32g (COŞKUNER & KARABABA, 2007), and one of the factors that can change it is the potential number of flowers that is determined during the plant's growth period. In addition, the thousand grain weight can be affected by the rate and duration of the grain filling period that occurs after pollination (MIRZAIE et al., 2020).

Pearson's correlation analysis showed that the grain yield of the crop at the time of April 15th (I) was determined by the stem diameter (SD), mass of capsule (MCAP), number of capsules that formed grains (NCFG), number of grains per plant (NGPP), weight of grains per plant (WGPP), and thousand grain weight (TGW) (Supplementary material ST 1). Similarly, the same characteristics determined the grain yield of linseed at the time of April 30th (II) (Suplementary material ST 2), except for the one thousand grain weight, which did not show significance, possibly due to the number of capsules that formed grains and the number of grains per plant that were strongly determinant for the expression of grain yield at this time.

On the May 15th (III) season, only the number stem branches and the plant stand showed significant positive correlations for linseed grain yield (Suplementary material ST 3). In the third sowing season, the plant stand had a strong and significant negative influence on the yield components, such as a reduction in the number of capsules, number of capsules that formed grains, and weight of grains per plant, if the plant stand and the number of branches were the only significant characters for the grain yield, since the plant stand is one of the main components of linseed productivity. Sowings on May 15th showed significant positive associations of strong magnitude between number of productive branches (NPB) and

Table 4. Mean comparison test for different variables in three linseed cultivars in Northwest of the State of Rio Grande do Sul, Brazil

Tabela 4. Teste de comparação de médias para diferentes variáveis em três cultivares de linhaça no Noroeste do estado do Rio Grande do Sul, Brasil

Cultivars	Variables				
	NSB [1]	NPB	GY	TGW	SD
IJUI001	4.45 a	10.51 a	1802.16 a	5.14 ab	2.21 a
IJUI002	4.49 a	9.73 a	1565.88 a	6.00 a	2.14 a
IJUI003	4.15 a	10.11 a	1759.75 a	4.91 b	2.19 a

[1] Means followed by the same lowercase letter in the column do not differ statistically at 5% probability by Tukey's tests. [1]NSB: Number of stem branches (unit); NPB: Number of productive branches (unit); GY: grain yield (kg ha^{-1}); TGW: Thousand grain weight (grams); SD: Stem diameter (mm).

[1] Médias seguidas pela mesma letra minúscula na coluna não diferem estatisticamente a 5% de probabilidade pelos testes de Tukey. [1]NSB: Número de ramos do caule (unidade); NPB: Número de ramos produtivos (unidade); RG: produtividade de grãos (kg ha^{-1}); TGW: Peso de mil grãos (gramas); SD: Diâmetro da haste (mm).

number of capsules (NCAP), mass of capsules (MCAP) and number of productive branches (NPB), and number of capsules (NCAP) and the capsule mass showed strong correlations with the number of capsules that formed grains (NCFG), number of grains per plant. In this context, on May 30th (IV) several characters were responsible for the grain yield of linseed, thus note that the plant stand, unlike the May 15th (III), did not negatively influence the components grain yield, just the number of capsules that did not form grains. Thus, the characters number of stem branches, number of productive branches, number of capsules per plant, mass of capsule per plant, number of capsules that formed grains, number of grains per plant, and weight of grains per plant were determinants for linseed grain yield.

The characteristics that were positively correlated with grain yield on May 30th (IV) and June 15th (V) are similar (Supplementary material ST 4 e 5); however, at the time V the results showed that the stem diameter exhibited a significant positive correlation with grain yield. More research is needed to verify the trend of contribution of this characteristic on the linseed yield, since few results are observed regarding the influence of the stem diameter in the production of linseed grains.

On June 30th (VI) the one thousand grain weight, weight of grains per plant, and the number of stem branches were substantial characteristics for the expression of linseed grain yield, since they exhibited a strong positive correlation (Supplementary material ST 6). This may have resulted from late sowings developing at high temperatures, which may have affected yield components such as number of capsules per plant, which, by the distribution of photoassimilates, promoted the highest weight of grains per plant and a thousand grain weight.

Sowing in the last season was characterized by positive correlations between the number of productive branches, number of capsules, mass of capsules, number of capsules that formed grains, number of grains per plant, and weight of grains per plant. The positive correlation of the number of capsules that formed no grains with grain yield can be explained by its correlation with the number of capsules per plant that exhibited a strong correlation with grain yield.

Naik et al. (2016), in a 30-year review, identified that the number of capsules is one of the characters with a direct positive relationship with grain yield. Dash et al. (2016) found a positive correlation between a thousand grain weight, number of grains per plant, and number of capsules per plant with linseed grain yield. In addition, several studies have also identified positive correlations between the number of capsules that formed grains and linseed grain yield (NAIK & SATAPATHY, 2002; RAO, 2007; GAURAHA & RAO, 2011), as well as the thousand grain weight with the linseed grain yield (MAHTO & RAHAMAN, 1998; NAIK & SATAPATHY, 2002; GAURAHA & RAO, 2011), which confirms the results in this study.

The results reveal the influence of sowing times on plant performance in morphology and productive response, especially when they are subjected to adverse factors such as frost and high temperatures, deficit and excess of precipitation. Early sowings of linseed are exposed to environmental damage, such as severe frost, and late sowings are subjected to water stress and high temperatures. The characteristics that determine the grain yield of linseed change according to the sowing time due to soil and climate changes. However, the weight of grains per plant was the yield component with the highest positive correlation with grain yield in all seasons, except for the one on May 15th (III). Stem diameter, mass of capsule, number of capsules that formed grains, number of grains per plant, one thousand grain weight, number of productive branches, number of capsules, number of stem branches, and plant stand were also determinant for grain yield at specific sowing times.

Conclusions

The sowing times influence the yield of linseed grains, with the sowings of April 30th and June 15th showing higher grain yield.

Linear trends change according to sowing times, such as stem diameter, mass and number of capsules, number and weight of grains per plant, which together define the productivity of linseed grains per unit area.

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