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Agronomic performance and yield of *Crambe abyssinica* hochst. in lowlands conditions at varying sowing seasons

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Abstract: Crambe (*Crambe abyssinica* Hochst), a species of the Brassicaceae family native to the Mediterranean region, is cultivated in tropical and subtropical areas and stands out for its short growing season, reaching physiological maturity in approximately 90 days. Its seeds contain a high oil content rich in erucic acid, used in the production of lubricants, anti-corrosives, and biodiesel, making it a promising alternative for industrial purposes. Despite its potential, few studies have been conducted on Crambe cultivation in southern Brazil, especially in floodplain areas. This study evaluated the development and productivity of the cultivar FMS Brilhante in Capão do Leão, Rio Grande do Sul, considering four sowing dates: June 13, July 16, August 16, and September 24, 2019. The experiment was conducted in a randomised complete block design with four replicates in a 4 × 4 factorial arrangement (four seed lots and four sowing dates). Plant height, stem diameter, number of branches and seeds per plant, and productivity (kg ha^{-1}) were evaluated. The best results occurred with sowing on June 13, with productivity exceeding 3,000 kg ha^{-1}, demonstrating its suitability for maximizing production in this region.

Keywords: Crambe, Sowing, Productivity, Germination, Growth cycle.

Introduction

Crambe (*Crambe abyssinica* Hochst), a member of the Brassicaceae family and native to the Mediterranean, is cultivated in tropical and subtropical regions (Queiroz et al., 2021, Sokólski et al., 2020). It is a winter annual with an early cycle: flowering begins about 35 days after emergence, and harvest occurs around 90 days (Maia et al., 2022, Brito et al., 2022). The plant features a single stem that branches near the ground into 30 or more primary branches, which further divide into secondary and tertiary branches (Santos et al., 2024), creating a bushy structure. Leaves are oval, asymmetric, and smooth-surfaced, with blades about 10 cm long and 7.6 cm wide, petioles are pubescent and roughly 20 cm long (Sória-Teixeira et al., 2024). The siliqua-type fruits are initially green, turning yellow at maturity. Seeds range from 0.8 to 2.6 mm in diameter, with size affected by seed number per plant, soil fertility, and water availability (Ugolini et al., 2023, da Silva et al., 2025).
Crambe is valued for its oily grains, with oil unsuitable for human consumption but used in industrial applications such as lubricants, anti-corrosive products, and synthetic rubber manufacturing (Sua et al., 2025, Berman, 2024). Its oil is particularly notable for its resistance to degradation, providing oxidation stability and significant advantages in terms of storage compared to other vegetable oils used in biodiesel production (Cavalheiro et al., 2023). This oil, containing between 50% and 60% erucic acid, is used in various products such as plastic films, plasticisers, nylon, adhesive glues, and electrical materials. The demand for erucic acid in the United States has driven studies on Crambe as a promising alternative, given its higher concentration of this acid compared to other oil sources (Uyaroğlu et al, 2022, Gongora et al., 2024). Additionally, its adaptation to areas with high rainfall in the United States represents a significant advantage (Finardi et al., 2023).
With productivity ranging from 1,000 to 1,500 kilograms per hectare in Brazil, reaching up to 2,300 kg ha-1 in experimental fields (Moura et al., 2023), and reports of yields exceeding 3,000 kg ha-1 in the United States and Europe (Hisano et al., 2022), crambe is recognised as a promising oilseed for the industry. With an average grain productivity of approximately 1500 kg ha-1 and oil productivity reaching 750 L ha-1 (Jankowski et al., 2022), crambe emerges as a promising alternative in the composition of the oil production matrix for biodiesel (de Marins et al., 2024).
For Crambe cultivation in Brazil, seed density between 8 and 22.5 kg ha-1, spacing of 0.21 m to 0.45 m between rows, and sowing depth of 0.03 m are recommended (Braga et al., 2022, Rosmaninho et al., 2023). The planting period usually occurs between March and May, extending until June. However, due to its tolerance to drought and cold, with a 90-day growth cycle, Crambe can be sown later, offering a viable alternative for regions subject to climatic risks (de Freitas Moura et al., 2022). On the other hand, in the Brazilian Midwest, the recommended sowing period is between April and July, varying according to the pre-planting rainfall incidence. In this region, row spacing varies from 17 to 45 centimeters while maintaining the recommended seed density and sowing depth (Alves et al., 2022, Pessoa et al., 2023).

In contrast, in Rio Grande do Sul, crop recommendations may differ from those in other regions of Brazil. This is particularly relevant in the southern half of the state, where lowland soils predominate (Subaşı, 2021). These soils are often characterized by low clay content, making them more susceptible to structural limitations, reduced water retention, and lower cation exchange capacity (Pacheco et al., 2024). Additionally, these areas are prone to water saturation, which can significantly impact crop establishment and development. These soils are moderately deep, imperfectly to poorly drained, and predominantly grayish due to gleiing (Queiroz et al., 2021). Developed from recent sediments, mainly from granite weathering, they extend across the coastal plain. A key feature is a leached horizon transitioning abruptly into a clayey horizon with noticeable variations in color, texture, and consistency. Found in flat relief areas, these soils are mostly acidic, with low to medium base saturation at the surface, increasing with depth (Loew et al., 2024).
Variations include medium-textured B horizons, gravelly soils with a well-developed A horizon, and soils where the gley horizon appears only in the lower B and C horizons. Some inclusions present high sodium levels in the B horizon or *Gleisoil's* in lower-lying areas. Poor drainage due to an impermeable B horizon is a major limitation, making these soils difficult to manage and prone to flooding. However, they hold high potential for irrigated rice cultivation, especially in rotation with pastures (Krzyzaniak et al., 2020).
Crambe abyssinica is a promising alternative for crop rotation in the lowlands of Rio Grande do Sul due to its ecosystemic benefits. Its ability to cover the soil reduces erosion, improves structure and fertility, and contributes to nutrient recycling (Prakhova et al., 2024, Oliveira et al., 2023). Additionally, its resilience and short growth cycle facilitate succession with other crops, enhancing the sustainability of the region's agricultural systems (Costa et al., 2019, Samarappuli et al., 2020, de Lima Mera et al., 2020).
In this sense, this study aimed to evaluate the development of Crambe cultivation in Capão do Leão, located in the southern zone of the state, in the lowlands, using different sowing times.

Results

Plant height of *Crambe abyssinica* varied significantly among the sowing seasons, reflecting the influence of temperature and photoperiod on vegetative development. The greatest mean height (109.08 cm) occurred in the July 16 sowing, followed by June 13 (100.51 cm), conditions likely characterized by milder temperatures and longer vegetative periods that favored stem elongation. Conversely, sowings on August 16 and September 24 presented reductions of 28% and 37%, respectively, relative to the highest mean, suggesting that delayed sowing exposed plants to shorter days and suboptimal thermal conditions for growth. The coefficient of variation (10.01%) indicates good experimental precision, and the overall mean height of 89.15 cm demonstrates that early sowing favors Crambe development in lowland environments. These results emphasize the importance of aligning sowing time with local climatic conditions to optimize crop establishment and productivity (Table 1).

Table 1. Plant height of Crambe (cm) from the FMS BRILHANTE cultivar produced from seeds of 4 lots cultivated in four sowing seasons in lowlands. Pelotas/RS, UFPel, 2022.

Sowing Seasons	Seed lots 1	2	3	4	MEANS
13/06	100.18	98.15	103.92	99.13	100.51 B
16/07	109.15	113.20	108.60	105.35	109.08 A
16/08	74.40	78.40	78.20	81.55	78.14 C
24/09	69.20	68.43	72.13	66.40	69.04 D
MEANS	89.20	89.54	90.71	88.28	
CV (%)	10.01				
Overall Mean = 89.15					

Means followed by the same letter in the column do not differ from each other at a 5% probability level according to Tukey's test, comparing the means of the lots within each sowing season.

The stem diameter of *Crambe abyssinica* exhibited a clear decline with later sowing dates, evidencing the sensitivity of this trait to environmental conditions during early development. The highest mean value (7.03 mm) was observed in the June 13 sowing, followed by July 16 (5.54 mm) and August 16 (5.21 mm), while the September 24 sowing resulted in the smallest stems (3.44 mm). These reductions may be attributed to the combined effects of shorter photoperiods, higher temperatures, and accelerated reproductive transition, which limit carbon allocation to stem thickening. Similar patterns have been reported in Crambe under suboptimal growing conditions, reinforcing that early sowing enhances vegetative vigor. The consistent ranking across seed lots suggests that environmental factors exerted greater influence than seed lot variability, emphasizing the importance of sowing time for maintaining robust plant architecture and supporting higher yield potential in lowland conditions (Table 2).
The number of branches per *Crambe abyssinica* plant showed a marked dependence on the sowing period, with the highest averages recorded in the June, July, and August sowings (13–14 branches) and a pronounced reduction in September (8 branches). Early sowing provided more favorable thermal and photoperiodic conditions, extending the vegetative phase and enabling greater branching, a trait closely linked to increased seed production. In contrast, the late sowing likely hastened reproductive transition under rising temperatures, restricting the emission of secondary branches. The overall

Table 2. The stem diameter (mm) of Crambe plants of the FMS BRILHANTE variety produced from seeds of 4 lots cultivated in four sowing periods in lowland soils. Pelotas/RS, UFPel, 2022

SOWING PERIODS	Seed lots 1	2	3	4	Means
13/06	7.25	7.30	6.48	7.10	7.03 A
16/07	5.68	5.43	5.38	5.68	5.54 B
16/08	4.48	5.28	5.30	5.78	5.21 B
24/09	3.58	3.10	3.43	3.58	3.442 C
Means	5.24	5.28	5.14	5.53	
CV (%)	14.09				
Overall Mean = 5.4					

Means followed by the same letter in the column. comparing the seed lot means within each sowing period. do not differ according to Tukey's test at a 5% probability level.
Source: The authors. 2024.

Table 3. The number of branches per Crambe plant (cm) of the FMS BRILHANTE cultivar produced from seeds of 4 lots cultivated in four sowing periods in lowland soils. Pelotas/RS. UFPel. 2022

Sowing periods	Seed lots 1	2	3	4	Means
13/06	13	14	13	13	13 A
16/07	14	15	14	12	14 A
16/08	12	15	16	14	14 A
24/09	8	8	8	8	8 B
MEANS	12	13	13	12	
CV (%)	16.52				
Overall Mean = 12.3					

Means followed by the same letter in the column. comparing the seed lot means within each sowing period. do not differ according to Tukey's test at a 5% probability level.

mean of 12.3 branches and the moderate coefficient of variation (16.52%) reflect adequate experimental control. These findings demonstrate that early sowing enhances canopy structure and yield potential of *Crambe* under lowland conditions, reinforcing the crop's adaptability to cooler seasons (Table 3).

Relative contribution of seed physiological performance variables

The number of seeds per *Crambe abyssinica* plant was strongly affected by the sowing period, with the earliest sowing on June 13 showing a markedly superior mean of 553 seeds, more than double that obtained in July (274) and over three times that of September (163). This pattern indicates that early sowing favored reproductive development, ensuring better pollination and seed filling under milder temperatures and longer photoperiods. Later sowings likely faced higher temperatures and accelerated maturation, reducing assimilate accumulation in reproductive structures. Despite the high coefficient of variation (47.4%), the overall mean of 303 seeds per plant underscores the potential of *Crambe* for high yield when established early in the season. These results confirm that sowing time is a decisive factor in optimizing reproductive efficiency and maximizing productivity in lowland environments (Table 4).

Table 4. The number of seeds per Crambe plant of the FMS BRILHANTE cultivar produced from seeds of 4 lots cultivated in four sowing periods in lowland soils. Pelotas/RS. UFPel. 2022.

Sowing periods	Seed lots 1	2	3	4	MEANS
13/06	586	549	499	576	553 A
16/07	295	227	214	362	274 B
16/08	209	249	255	171	221 B
24/09	92	101	162	266	163 B
MEANS	295	289	283	344	
CV (%)	47.4				
Overall Mean = 303					

Means followed by the same letter in the column do not differ from each other at a 5% probability level according to Tukey's test. comparing the means of the lots within each sowing season .

Seed productivity of *Crambe abyssinica* showed a pronounced response to sowing periods, with the earliest date (June 13) yielding the highest mean productivity (3,098.5 kg ha^{-1}), followed by July (1,571.1 kg ha^{-1}), August (1,209.3 kg ha^{-1}), and September (856.1 kg ha^{-1}). The decline in yield with later sowings reflects the sensitivity of *Crambe* to thermal and photoperiodic stress, which likely reduced flowering duration and seed filling efficiency. Early sowing coincided with favourable climatic conditions that supported better vegetative growth, greater branching, and higher seed set, directly translating into superior yield performance. Although the coefficient of variation was relatively high (48.7%), the trend across sowing periods was consistent, confirming the advantage of early planting in maximising yield potential. These results highlight that June sowing ensures the most productive cycle for *Crambe* under lowland conditions in southern Brazil (Table 5).

Table 5. Crambe seed productivity (Kg/ha) of the FMS BRILHANTE cultivar produced from seeds of 4 lots cultivated in four sowing periods in lowland soils. Pelotas/RS. UFPel. 2022

Sowing periods	Seed lots				
	1	2	3	4	Means
13/06	3245.6	3127.4	2857.4	3163.6	3098.5 A
16/07	1729.2	1303.4	1198.5	2053.2	1571.1 B
16/08	1181.8	1328.6	1398.9	927.8	1209.3 B
24/09	510.3	699.8	856.4	1358.1	856.1 B
MEANS	1666.7	1614.8	1577.8	1875.7	
CV (%)	48.7				
Overall Mean = 1683.7					

Means followed by the same letter in the column do not differ from each other at a 5% probability level according to Tukey's test. comparing the means of the lots within each sowing season.

The duration of the period between emergence and physiological seed maturity of *Crambe abyssinica* decreased progressively with later sowing dates, evidencing a strong environmental control over the crop's phenological development. Plants sown on June 13 completed their cycle in approximately 125 days, while those sown on September 24 required only about 65 days to reach maturity. This reduction reflects the influence of increasing temperatures and decreasing photoperiods, which accelerate reproductive transition and shorten the grain-filling phase. Although shorter cycles may allow harvest before excessive rainfall, they limit biomass accumulation and yield potential. Therefore, early sowing not only extends the vegetative period but also supports higher productivity, confirming the adaptive advantage of establishing *Crambe* under cooler and more stable climatic conditions in lowland regions (Figure 1).

Discussion

The results indicate that the first two sowing periods resulted in taller Crambe plants, which can be attributed to the plant's indeterminate growth pattern. The extended period between emergence and seed maturity in these sowing periods allowed for prolonged vegetative growth. This observation aligns with the hypothesis that the crop, when sown earlier, develops under lower temperatures, consequently requiring a longer time to accumulate the necessary thermal units for the onset of flowering (Kurt et al., 2022). Comparing the results of the second sowing date (July 16) with the first (June 13), which recorded an average plant height of 100.51 cm - the second-highest observed - a relative increase of 8% was noted. This difference may be attributed to variations in environmental factors, particularly temperature and light availability, which play a crucial role in Crambe development.

Crambe exhibits a thermal requirement of approximately 6.91ºC per day and a base temperature of 9.5ºC (Zu et al., 2021), indicating its dependence on cumulative heat units. However, plants sown on August 16 exhibited a 28% reduction in height compared to those sown on July 16. This suggests that later sowing periods may limit the vegetative phase, possibly due to an accelerated transition to reproductive development. Regarding stem diameter, a significant effect of sowing date was observed (Table 2). The data indicate that plants sown on June 13, 2019, exhibited an average stem diameter 51% larger than those from the final sowing period. The second and third sowing dates did not differ statistically in stem diameter, however, their combined average was 36% greater than that of the fourth sowing period. Conversely, when comparing the first sowing date with the combined average of the second and third, a 24% reduction was noted.

The sowing date also had a significant impact on the number of branches per Crambe plant (Table 3). The fourth sowing period resulted in the lowest number of branches per plant, averaging eight branches, 41% lower than the mean observed for the other sowing periods. The first three sowing periods did not exhibit statistically significant differences, averaging approximately 14 branches per plant. This stability in branch production across early sowing dates may be attributed to the species' high plasticity and the influence of plant spacing. As an autumn-winter crop in Brazil, Crambe performs optimally under moderate temperatures, around 15°C (Sória-Teixeira et al., 2024), which were likely more favourable during earlier sowing periods than in the final sowing.

Regarding the number of seeds per plant, a significant sowing period effect was observed (Table 4). The first sowing period yielded the highest seed count per plant, approximately 60% higher than the average of the subsequent three sowing periods, which did not show statistical differences among themselves. This trend correlates strongly with the seed productivity data. A similar pattern was reported by Sokólski (2020), who observed a decline in yield components as sowing dates progressed, with the earliest sowing yielding the best results.

Seed productivity (kg/ha) was significantly affected by sowing date (Table 5). The first sowing period (June 13) resulted in the highest seed yield, reaching 3,098.5 kg/ha, significantly outperforming the other sowing dates. No statistical differences in productivity were observed among the last three sowing periods. When comparing the first sowing date with the average productivity of the following three periods, the early sowing led to a 61% increase, representing an additional 1,886.4 kg/ha. Although only the first sowing period showed statistically significant differences, the productivity trend was consistent with Jankowski (2022), who reported a progressive decline in Crambe yield as sowing dates advanced in Cascavel, PR.

Finally, the duration between seedling emergence and physiological seed maturity decreased progressively with later sowing dates. This trend is likely due to the Crambe response to accumulated thermal units (degree-days) required for maturity. Pessoa et al., (2023) reported a similar pattern, where the Crambe growth cycle ranged from 136 to 74 days, shortening as sowing dates advanced. These findings indicate that Crambe adjusts its development rate according to environmental conditions, with later sowing dates accelerating the transition to physiological maturity. Pereira et al. (2022) observed that Crambe abyssinica plants grown under water regimes between 59% and 61% of field capacity produced seeds with higher physiological quality (Panozzo et al., 2025, Dorr et al., 2023). This result was evidenced by superior performance in germination tests, first germination count, and emergence speed index, indicating that adequate water availability directly influences seed viability and vigor. These findings corroborate the results of the analyzed study, reinforcing the importance of water management in crambe cultivation.

Materials and Methods

Plant material and experimental setup and climatic data monitoring

The study was conducted in an experimental area in Capão do Leão, Palma region, in the Southern Half of Rio Grande do Sul. This area has floodplain soil and is part of a floodplain zone. Part of the research also took place in the Seed Didactic Analysis Laboratory of the Faculty of Agronomy Eliseu Maciel at the Federal University of Pelotas, on the Capão do Leão campus. Seeds of the Crambe FMS Brilhante cultivar, produced by the MS Foundation, were sown in four periods: June 13, 2019, July 16, 2019, August 16, 2019, and September 24, 2019. Planting was done in plots 5 meters long with 12 rows, row spacing of 17 cm, and sowing depth of 0.03 m. Plant density was about 14 plants per linear meter, or about 80 plants per square meter. The experimental design was randomized blocks, with four replications, in a 4x4 factorial scheme (4 seed lots and 4 sowing times).

Measurements of plant characteristics

At the physiological maturity stage of the seeds, a phenological evaluation of the plants was carried out. Ten plants per plot were collected and evaluated, observing the following variables: Plant height: measured from the ground to the apex of the plant, in centimeters, Plant diameter: measured at the base of the plant stem, in millimeters, Number of branches per plant: direct manual counting of plant branches, Number of seeds per plant: direct manual counting of seeds produced per plant, Productivity in kg per hectare: obtained by multiplying the average mass of seeds produced per plant by the plant population density. The result was expressed in kilograms of seeds per hectare.

Statistical analysis

The data obtained were subjected to homogeneity (Bartlett's test) and normality of error (Shapiro-Wilk test) assessments. The collected data were analyzed for homogeneity and subsequently subjected to analysis of variance ($p \leq 0.05$). When significant, the means of the factors sowing times and seed lots were compared using the Tukey test ($p \leq 0.05$). All statistical analyses were performed using the Genes statistical software R (R Core Team, 2014).

Conclusions

The first sowing period (June 13) was the most favorable for cultivating Crambe under lowland conditions in southern Rio Grande do Sul. This period produced the highest seed yield, averaging over 3,000 kg per hectare, showing its suitability for maximizing production. The number of seeds per plant is a critical factor influencing the yield in Crambe cultivation. The highest number of seeds per plant was observed in the first sowing period (June 13), further reinforcing its role as the optimal sowing time for achieving superior yield outcomes. The time from Crambe seedling emergence to seed maturity varied significantly, ranging from 124 to 59 days, depending on the sowing date. This variation highlights the influence of sowing timing on the growth cycle and physiological development of Crambe, with earlier sowing leading to a longer maturation period.

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