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Article

Optimization of Irrigation in Crambe (*Crambe abyssinica*) for Enhancing Biofuel Production

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RESUMO

O crambe (*Crambe abyssinica*), pertencente à família Brassicaceae e nativo da região do Mediterrâneo, destaca-se como uma cultura agroenergética promissora. Seu cultivo em larga escala ocorre principalmente no México e nos Estados Unidos, tendo sido introduzido no Brasil em 1995. A demanda por fontes de energia sustentáveis vem crescendo devido ao caráter finito do petróleo, sendo os óleos vegetais alternativas para a produção de biodiesel, contribuindo para a redução das emissões de CO_2. O crambe apresenta ciclo curto (90 dias), produtividade de sementes entre 1.000 e 1.500 kg ha^{-1}, baixo custo de produção e elevado teor de óleo (26–38%), com aplicações industriais e subprodutos aproveitáveis. A otimização da irrigação no cultivo do crambe é fundamental para aumentar a produção de biocombustível, por meio da avaliação do impacto dos intervalos de irrigação no desempenho agronômico. Um experimento de campo foi conduzido na UEPB (Lagoa Seca, PB, Brasil), sob clima tropical úmido, em Neossolo Regolítico Eutrófico. O delineamento experimental foi em blocos casualizados, em arranjo fatorial 3×4 (intervalos de irrigação: 1, 2 e 3 dias; 4 repetições), com parcelas de 20 m². A irrigação foi realizada por sistema de gotejamento, com base no balanço hídrico, e a adubação consistiu na aplicação de 30 t ha^{-1} de esterco bovino, utilizando-se a cultivar FMS Brilhante. As seguintes características foram avaliadas aos 60 e 75 dias após a semeadura: altura de plantas, diâmetro do caule, área foliar, número de ramos, número de cápsulas, biomassa, massa

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de mil sementes e produtividade. Os dados foram analisados por ANOVA, teste de Tukey (5%) e regressão, utilizando o programa SISVAR. O intervalo de irrigação de 1 dia aumentou a altura das plantas (1,05 m), o número de ramos (10,25), a área foliar (148,15 cm²), a massa de mil sementes (7,37 g) e a produtividade (297,31 kg ha⁻¹). O intervalo de 2 dias proporcionou maior diâmetro do caule (7,18 mm), maior massa de mil sementes (7,90 g) e maior biomassa (13,98 g/planta). O intervalo de 3 dias aumentou o número de cápsulas (549,88), porém reduziu a produtividade (212,80 kg ha⁻¹).
Palavras-chave: biocombustível; irrigação; manejo agronômico.

ABSTRACT

Crambe (*Crambe abyssinica*), from the Brassicaceae family and native to the Mediterranean region, stands out as a promising agroenergy crop. Its large-scale cultivation occurs mainly in Mexico and the USA, having been introduced to Brazil in 1995. The demand for sustainable energy sources is growing due to the finite nature of petroleum, with vegetable oils serving as alternatives for biodiesel production, helping reduce CO_2 emissions. Crambe has a short cycle (90 days), seed yield of 1,000–1,500 kg ha⁻¹, low production cost, and high oil content (26–38%), with industrial applications and useful by-products. Optimizing irrigation in crambe cultivation is key to enhancing biofuel production by assessing the impact of irrigation intervals on agronomic performance. A field experiment was conducted at UEPB (Lagoa Seca, PB, Brazil) under a humid tropical climate, in Eutrophic Regolithic Neosol. The experimental design was a randomized block, in a 3×4 factorial arrangement (irrigation intervals: 1, 2, and 3 days; 4 replications), with plots of 20 m². Irrigation was performed by drip system, based on water balance, with fertilization using 30 t ha⁻¹ of cattle manure, cultivar FMS Brilhante. The following traits were evaluated at 60 and 75 days after sowing: plant height, stem diameter, leaf area, number of branches, number of capsules, biomass, thousand-seed weight, and yield. Data were analyzed by ANOVA, Tukey test (5%), and regression using SISVAR. An irrigation interval of 1 day increased plant height (1.05 m), number of branches (10.25), leaf area (148.15 cm²), thousand-seed weight (7.37 g), and yield (297.31 kg ha⁻¹). The 2-day interval improved stem diameter (7.18 mm), thousand-seed weight (7.90 g), and biomass (13.98 g/plant). The 3-day interval increased the number of capsules (549.88), but reduced yield (212.80 kg ha⁻¹).
Keywords: biofuel; irrigation; agronomic management.

Introduction

Crambe (*Crambe abyssinica*), a member of the Brassicaceae family and native to the Mediterranean region, has emerged as a crop of significant agroenergy interest (Maia et al., 2023; Werncke et al., 2023; Santos et al., 2024). Its large-scale cultivation is primarily concentrated in Mexico and the United States, with its introduction to Brazil occurring only in 1995 at the Fundação MS research station in Maracaju, Mato Grosso do Sul (Souza et al., 2021; Moura et al., 2022; Silva et al., 2024).

As a relatively new crop in Brazil, there is a pressing need for studies to provide scientific data on its management and cultural practices, enabling producers to adopt efficient and appropriate techniques (Oliveira et al., 2023; Allein et al., 2024). The growing demand for sustainable energy alternatives is closely tied to the finite nature of petroleum reserves, a non-renewable resource that remains the primary energy source and the foundation for fuels such as diesel (Furtado & Paim, 2024). Partially or fully replacing fossil fuels with renewable sources, such as vegetable oils, is a strategic approach to reducing CO_2 emissions and mitigating environmental impacts (Murta et al., 2023). Vegetable oils were initially used in their crude form in compression-ignition engines, but technological advancements have led to the prominence of biodiesel as a viable alternative (Honório, 2024). Biodiesel is typically produced through transesterification, a process involving the reaction of vegetable oils or animal fats with alcohol in the presence of an acidic or basic catalyst, yielding a product with properties similar to diesel and glycerol as a byproduct, which is utilized in cosmetics and hygiene products (Farouk et al., 2024; Geraldo Junior et al., 2025).

In this context, crambe exhibits notable agronomic and industrial characteristics: a short growth cycle (approximately 90 days), high seed productivity (1,000–1,500 kg ha⁻¹), low production costs, and a high oil content (26–38%) (Pitol, 2008; Silveira & Novais, 2025). Beyond biodiesel production, the oil's high erucic acid content (50–60%) makes it valuable for the plastics and lubricant industries. Additionally, the cake resulting from oil extraction, containing approximately 30–32% crude protein, can be used as feed for ruminants (Mendonça et al., 2015; Li et al., 2019).

Research indicates that seed production and oil composition in oilseed crops are influenced by environmental and nutritional factors. For instance, experiments with sunflower (Helianthus annuus) by Castro et al. (1998) demonstrated increased grain yield with nitrogen applications up to 90 kg ha^{-1}. The quality of biodiesel, in turn, depends on the fatty acid profile, which affects parameters such as iodine value, cetane number, calorific value, specific consumption, low-temperature performance, and viscosity (Ferreira & Furtado, 2025). Guimarães et al. (2023) and Sabaghnia & Janmohammadi (2024) found that salinity reduces the concentrations of oleic, linoleic, and eicosanoic acids but has a minimal impact on erucic acid levels.

Given these considerations, understanding how biotic and abiotic factors influence the metabolism and oil composition of crambe is critical for optimizing its production and quality. The scarcity of studies on this crop, combined with its agroenergy potential, underscores the importance of research that integrates agronomic and industrial aspects to establish crambe as a sustainable alternative.

Material and Methods

The experiment was conducted in a field setting at the Centro de Ciências Agrárias e Ambientais (CCAA), Campus II of the Universidade Estadual da Paraíba (UEPB), located at Sítio Imbaúba, Lagoa Seca, Paraíba, Brazil, at an average altitude of 634 m. The region has a humid tropical climate (As', Köppen classification), with an average annual temperature ranging from 22 to 26 ºC and mean precipitation of 990 mm. The terrain is gently undulating, and the soil is classified as a Eutrophic Regolithic Neosol. Irrigation was applied using a localized drip system, with water management based on the soil water balance determined using a Class A evaporation pan. Soil preparation involved plowing and harrowing, followed by fertilization with cattle manure at a rate of 30 t ha^{-1}. Initial irrigation raised the soil water content to field capacity, creating suitable conditions for germination of seeds of the FMS Brilhante cultivar, which were sown along contour lines at a depth of 1 cm.

Irrigation water was sourced from a nearby reservoir and delivered to the experimental area via an electric pump, distributed to the plots through drip emitters. The applied water volumes were calculated based on soil water availability, determined by daily measurements and adjusted using the soil water retention curve developed according to the Van Genuchten model (Libardi, 2000). The experimental design was a randomized complete block with three blocks and 12 treatments arranged in a 3 x 4 factorial scheme, comprising three irrigation intervals (1, 2, and 3 days) and four replicates, with plots measuring 20 m².

The following variables were evaluated: plant height, stem diameter, leaf area, number of branches and capsules, aboveground biomass, 1000-grain weight, and yield adjusted to 11% moisture content, with data collected at 60 and 75 days after sowing. The data were subjected to analysis of variance (ANOVA) and Tukey's test at a 5% significance level, with regression analysis performed for the quantitative factor using the SISVAR software.

Results

The data were subjected to statistical analysis using the SISVAR software (ESAL, Lavras/MG) through analysis of variance (ANOVA) and the application of the F-test to compare means between treatments. For the quantitative factor, regression analysis was performed following the methodology described by Ferreira (2000), with results presented in Table 1, referring to 60 days after sowing (DAS).

Height

The results of the analysis of variance (ANOVA) for crambe plant height, presented in table 1, show a statistically significant difference due to the different irrigation intervals applied. The comparison of treatment means, as well as the regression analysis for the quantitative factor of irrigation interval, related to plant height at 60 days after sowing (DAS), are detailed and illustrated in Figure 1. It was observed that the maximum plant height was 1.05 m, achieved with the daily irrigation interval (1 day).

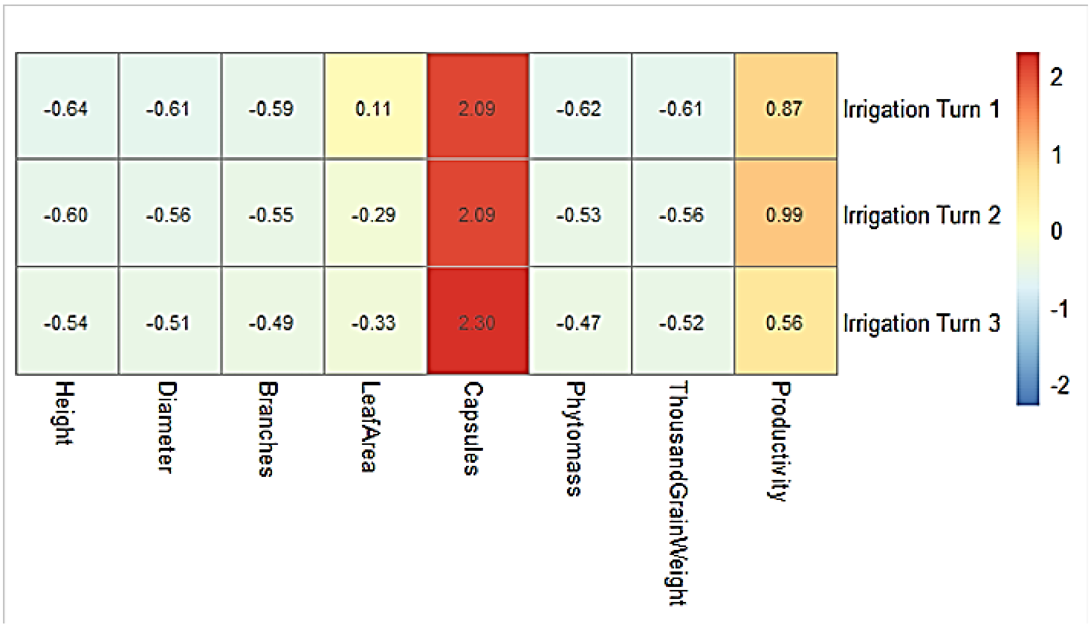

Figure 1. ANOVA of agronomic variables of Crambe FMS Brilhante under supervision regimes at 60 and 75 DAS. Source: Researcher's Data

A decreasing linear trend in plant height was observed with increasing intervals between irrigation events, indicating that the best water management for crambe height at 60 days after sowing (DAS) was the daily irrigation regime. The regression curves and their corresponding equations, presented in chart (1), confirm this trend, with plant height decreasing to 0.91 m under the irrigation regime applied every three days.

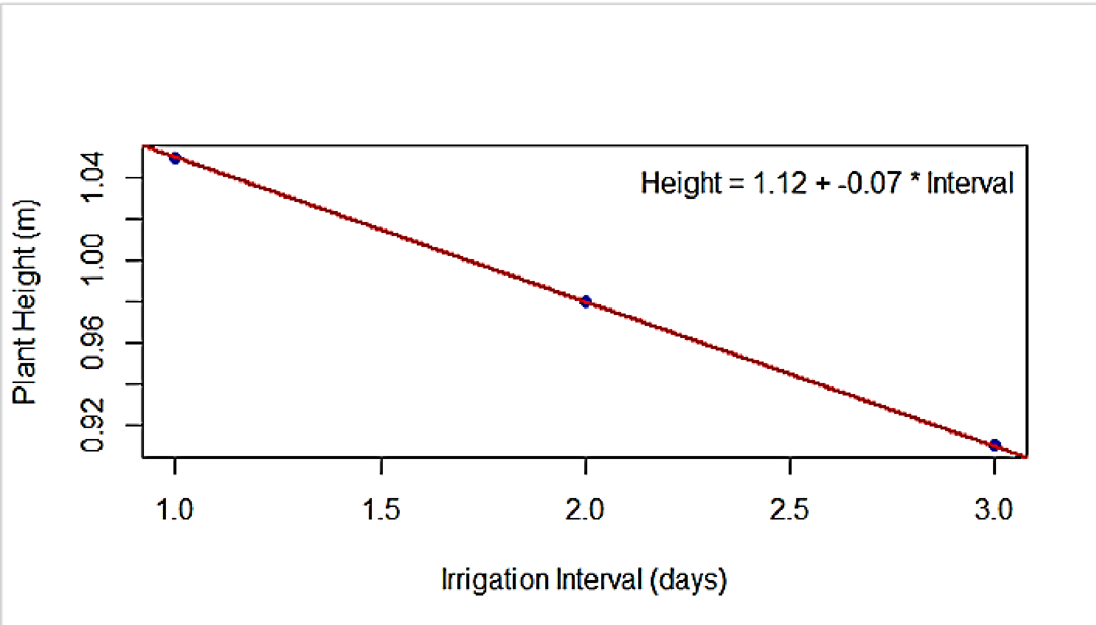

Chart 1. Plant Height vs Irrigation Interval. Source: Researcher's Data

Consistent results were reported by Formiga and Silva (2016), who observed an upward and quadratic growth pattern in crambe plant height up to the application of 30 t ha^{-1} of cattle manure, achieving an average height of 1.18 m, followed by a decline at higher fertilization levels (40 and 50 t ha^{-1}), with heights of 1.17 m and 1.07 m, respectively. These findings indicate that the optimal level of nitrogen fertilization for crambe height corresponds to 30 t ha^{-1} of cattle manure.

Similarly, Chaves and Ledur (2014), in a study conducted in an experimental field in the state of Paraná, found that plant height was significantly influenced by phosphorus application and the interaction between nitrogen and phosphorus. However, Maekawa Júnior et al. (2010) did not identify a significant effect of fertilization on crambe plant height, suggesting possible variations due to edaphoclimatic conditions and management practices.

Diameter

Regarding the stem diameter of the crambe crop, a statistically significant difference was observed due to the different irrigation intervals applied. The summary of the analysis of variance (ANOVA) concerning the effect of treatments on stem diameter is presented in Table 1. The treatment means, as well as the regression analysis for the quantitative factor of irrigation intervals, related to stem diameter at 60 days after sowing (DAS), are shown in figure (1) and chart (2).

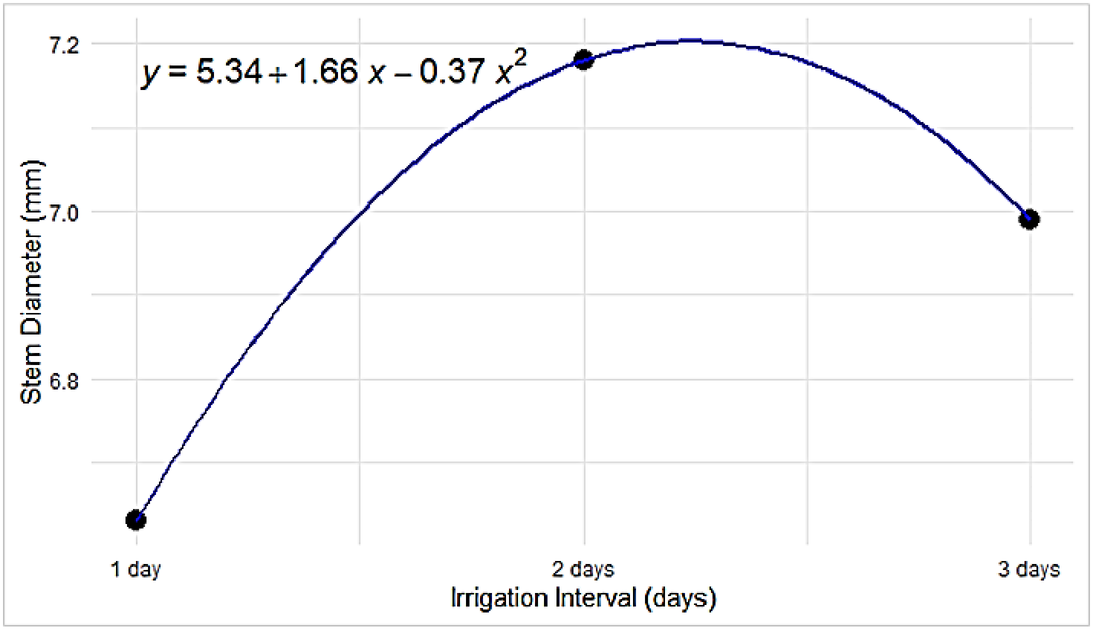

Chart 2. Effect of Irrigation Interval on the Stem Diameter of Crambe. Source: Researcher's Data

Significant variations were observed in the mean stem diameters at 60 days after sowing (DAS), with the maximum value of 7.18 mm recorded for the crop subjected to a dose of 30 t ha^{-1} of cattle manure. It is noteworthy that Formiga and Silva (2016), although they did not identify statistically significant differences in the values related to the stem diameter at 60 DAS, reported maximum mean diameters of 8.71 mm for the same fertilization level.

The regression analysis, shown in chart (3), reveals a quadratic upward trend in stem diameter up to the irrigation interval of every two days, with a mean value of 7.18 mm, followed by a reduction observed in the irrigation interval of every three days, which presented a mean diameter of 6.99 mm.

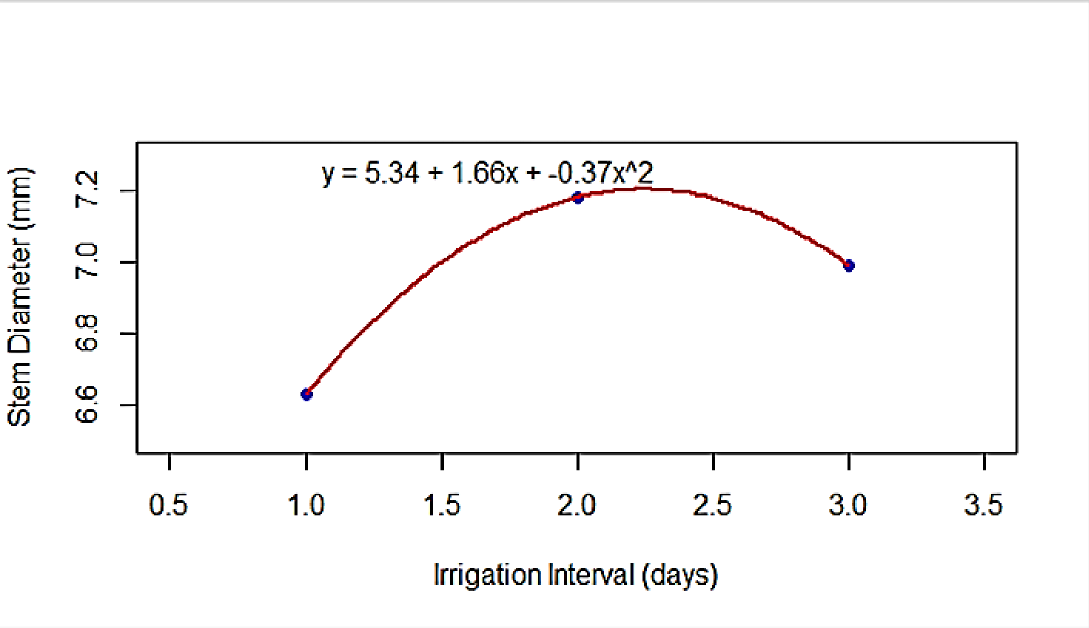

Chart 3. Quadratic Regression of Stem Diameter vs Irrigation Interval. Source: Researcher's Data

These results suggest that water management positively influenced stem diameter development up to a certain point, indicating that longer intervals between irrigations may compromise stem thickness and, potentially, the overall development of the crop.

Number of Branches

There were differences in the means related to the number of branches at 60 days after sowing (DAS), whose behaviors can be observed in Figure (2). The best irrigation interval for the number of branches variable was 1 day at 60 DAS with 10.25 branches.

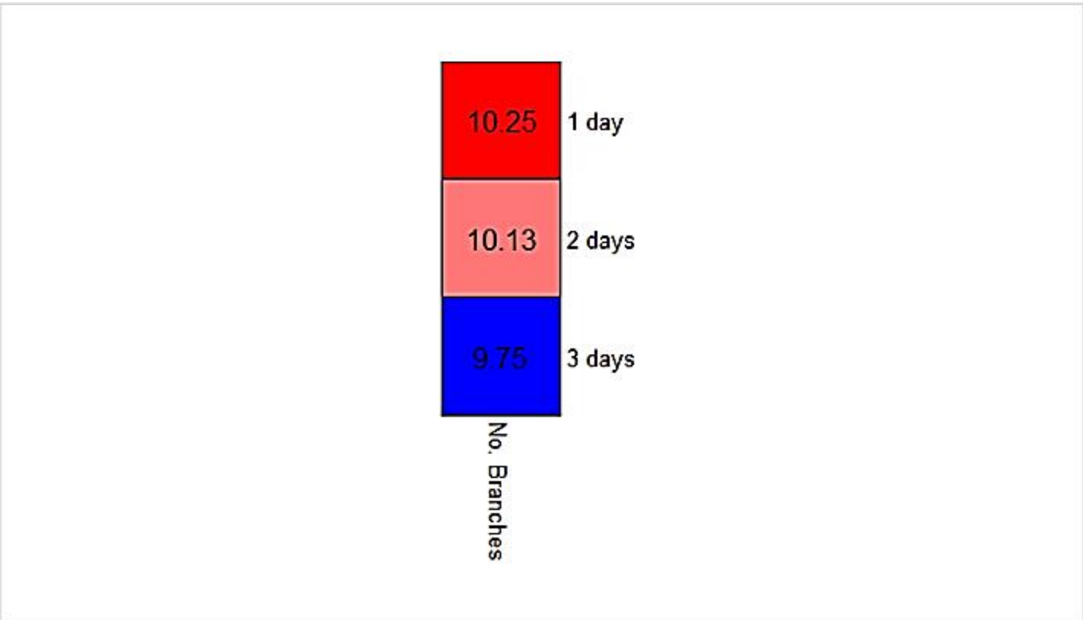

Figure 2. Heatmap of Number of Branches vs Irrigation Interval at 60 DAS. Source: Researcher's Data

Chaves and Ledur (2014) found in a study conducted in the state of Paraná that the number of branches was significantly influenced, at the 1% level, by the application of nitrogen and phosphorus in the crambe crop. Formiga and Silva (2016) identified differences in the means related to the number of branches at 60 days after sowing (DAS). The best levels of fertilization with cattle manure for the number of branches variable were 30 t ha^{-1} of cattle manure at 60 DAS with 13.67 branches.

Data Leaf Area

Statistically significant differences were observed in the leaf area of crambe depending on the different irrigation intervals. The largest leaf area was obtained with the daily irrigation interval, under the application of 30 t ha^{-1} of cattle manure. Similar results were reported by Formiga and Silva (2016), who, in an experimental study in Lagoa Seca/PB, recorded an average leaf area of 142.33 cm^2 at 30 DAS.

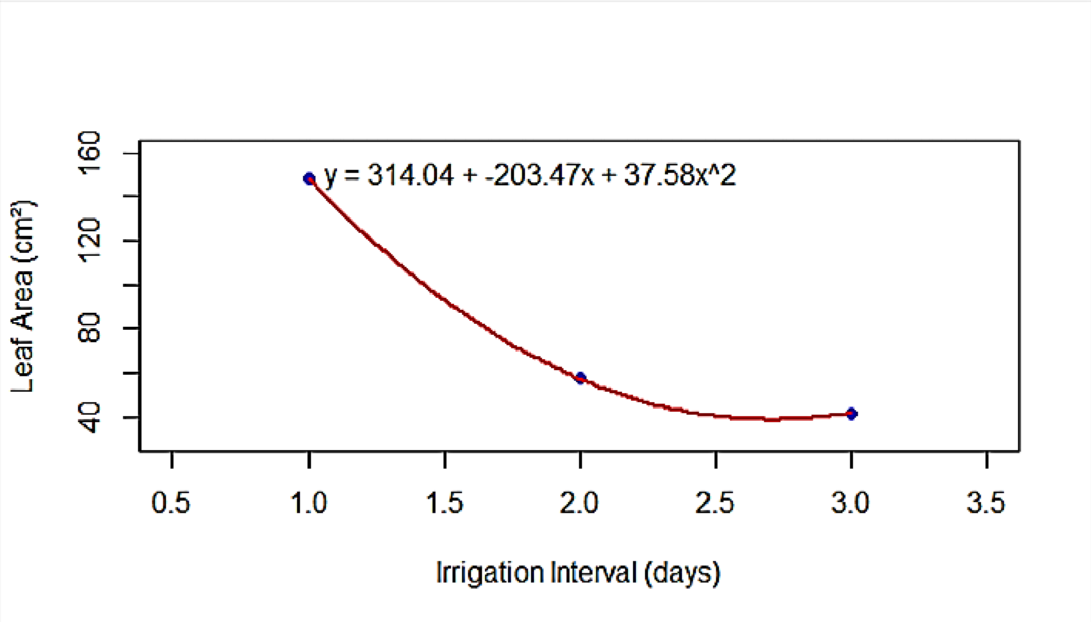

Chart 4. Quadratic Regression of Leaf Area vs Irrigation Interval at 60 DAS. Source: Researcher's Data

The regression presented in Chart 4 indicates a quadratic decreasing trend in leaf area as a function of the increase in the interval between irrigation events, culminating in a reduction to 41.85 cm^2 in the regime with a 3-day interval. In addition, at 60 days after sowing (DAS), the highest dry biomass weight occurred with the 2-day irrigation interval, at 13.98 g/plant. Freitas et al. (2013) found a crambe plant biomass of 8.7 g with a row spacing of 51 cm.

Thousand-grain weight

For the thousand-grain weight, there was significance related to the 2-day irrigation interval, with 7.9 g/plant (Figu. The lowest thousand-grain weight was observed with the 3-day irrigation interval. Freitas et al. (2013) found a thousand-grain weight of crambe plants equal to 8.7 g with a row spacing of 51 cm. Likewise, Formiga and Silva (2016) found significance related to fertilization levels with cattle manure at 40 t ha^{-1}, with 12.47 g/plant.

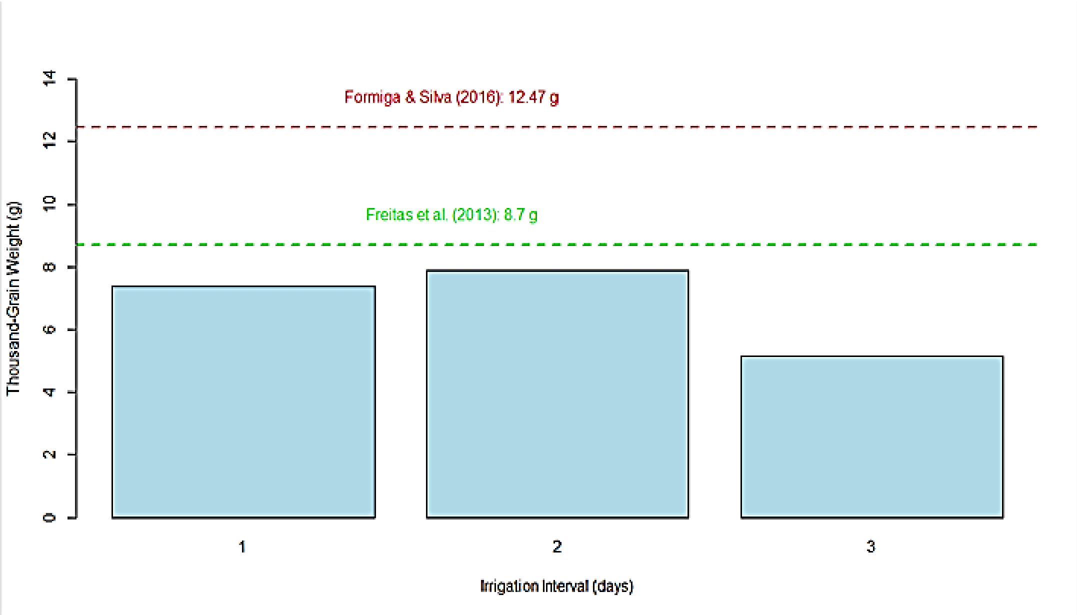

Chart 5. Thousand-Grain Weight vs Irrigation Interval at 60 DAS. Source: Researcher's Data

Productivity

For productivity, there was a difference related to the 1-day irrigation interval, with 297.31 kg ha^{-1} (Figure 3). The lowest productivity was observed with the 3-day irrigation interval, at 212.80 kg ha^{-1}. Freitas et al. (2013) found a crambe productivity equal to 8.7 g with a row spacing of 51 cm. Formiga and Silva (2016) reported productivity with cattle manure fertilization at 40 t ha^{-1}, achieving 368.79 kg ha^{-1}, while the lowest productivity was observed at the 10 t ha^{-1} level, with 219.70 kg ha^{-1}.

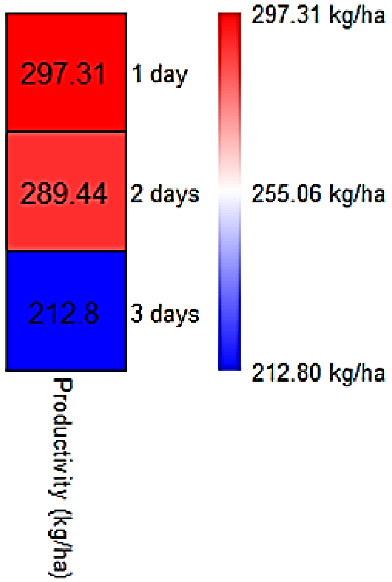

Figure 3. Heatmap of Productivity vs Irrigation Interval at 60 DAS. Source: Researcher's Data

Maekawa Junior (2010), studying the productivity of the crambe crop in relation to fertilization, spacing, and plant density, identified that a spacing of 0.17 m resulted in a grain yield above 1500 kg ha^{-1}. However, Kruger et al. (2011) observed that plant density did not influence the grain productivity of the canola crop. On the other hand, Santos et al. (1990) found that the grain yield of canola increased with the reduction of spacing and sowing density.

Conclusions

The application of varying irrigation intervals significantly influenced the agronomic performance of the crambe crop. The 1-day irrigation interval enhanced plant height (reaching 1.05 m), number of branches (10.25), leaf area (148.15 cm^2), thousand-grain weight (7.37 g), and productivity (297.31 kg ha^{-1}), demonstrating its effectiveness in optimizing these parameters. The 2-day irrigation interval proved most beneficial for stem diameter (7.18 mm), thousand-grain weight (7.90 g), and plant dry biomass (fitomassa) (13.98 g/plant), indicating a favorable impact on structural and biomass-related traits.

Conversely, the 3-day irrigation interval resulted in the highest number of capsules (549.88), suggesting a specific advantage for reproductive output under this regime, though it coincided with the lowest values for most other variables, including productivity (212.80 kg ha^{-1}). Notably, the 1-day irrigation interval yielded the highest average productivity of 297.31 kg ha^{-1}, underscoring its superiority for overall yield.

Throughout the cultivation period, no incidence of pests or diseases was observed, contributing to the consistent performance of the crop across all irrigation treatments. These findings highlight the importance of tailored irrigation management to maximize specific agronomic traits and overall productivity in crambe cultivation.

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