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# Nitrogen rate and seed density in irrigated rice: Blast severity, effects on yield and grain protein

## Tasa de nitrógeno y densidad de siembra en arroz de regadío: Severidad del añublo, efectos sobre el rendimiento y la proteína del grano

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## ABSTRACT

Blast is the most important rice disease worldwide, primarily due to the interaction of climatic and the environment factors nitrogen fertilization management, and sowing densities, all of which favor the disease progression and directly affect productivity. Here, we evaluated the effect of nitrogen (N) rates and seed densities (SD) on the Area Under the Disease Progress Curve (AUCPD) of rice blast, caused by the pathogen *Pyricularia grisea*, in rice grown under flood irrigation during the vegetative and reproductive stages, as well as its influence on grain yield and protein content. The experiment, carried out under field conditions, was organized in a randomized complete block design, in a in a 2 x 5 x 4 factorial scheme, with four replications. The results show that high ND and SD favored an increase in the AUDPC of leaf and panicle blast, between the two rice cultivars (BRS A704 and BRS A706 CL) affecting yield and crude protein (CP) content in the grain. However, ND above 140 kg ha$^{-1}$ led to an increase in yield and protein content for both cultivars, inserted in an area with blast and red rice infestation.

**Keywords:** Area under disease progress curve; fertilizer-disease interaction; flooded rice systems; infesting plants; nitrogen fertilization; *Oryza sativa; Pyricularia grisea*.

## RESUMEN

El añublo es la enfermedad más importante del arroz en todo el mundo, debido principalmente a la interacción de los factores climáticos y ambientales, la gestión de la fertilización nitrogenada y las densidades de siembra, los cuales favorecen la progresión de la enfermedad y afectan directamente a la productividad. Aquí, evaluamos el efecto de las dosis de nitrógeno (N) y las densidades de siembra (SD) sobre el Área Bajo la Curva de Progreso de la Enfermedad (AUCPD) del añublo del arroz, causada por el patógeno *Pyricularia grisea*, en el arroz cultivado bajo riego por inundación durante las etapas vegetativa y reproductiva, así como su influencia sobre el rendimiento de grano y el contenido de proteína. El experimento, realizado en condiciones de campo, se organizó en un diseño de bloques completos al azar, en un esquema factorial 2 x 5 x 4, con cuatro repeticiones. Los resultados muestran que altos ND y SD favorecieron un incremento en el AUDPC del añublo de hoja y panícula, entre las dos variedades de arroz (BRS A704 y BRS A706 CL) afectando el rendimiento y el contenido de proteína cruda (PC) en el grano. Sin embargo, la DN por encima de 140 kg $ha^{-1}$ condujo a un aumento del rendimiento y del contenido de proteína en ambos cultivares, insertados en una zona con infestación de añublo y arroz rojo.

**Palabras clave:** Área bajo la curva de progreso de la enfermedad; fertilización nitrogenada; interacción fertilizante-enfermedad*; Oryza sativa;* plantas infestantes*; Pyricularia grisea;* sistemas de arroz inundados**.**

## INTRODUCTION

Rice (*Oryza sativa L.*) is a staple food for over 3.5 billion people globally and the third most consumed cereal, after maize and wheat (Ahmed *et al.*, 2024). Estimated world rice production for the 2024/25 harvest is expected to reach 719.9 million tons, with India and China being the largest contributors with around 29.1% and 28.8% (FAO, 2024).

To meet increasing demand, various production methods are employed, including non-flooded mulch irrigation (Zhang *et al.*, 2019), alternate wetting and drying (Lampayan *et al.*, 2015), and rainfed systems (Hoshikawa *et al.*, 2018). However, the water-stable flooded rice system remains the most widely used cultivation method worldwide (Luo *et al.*, 2022). One of the largest rice producers outside of Asia, Brazil plays a significant role in global rice production, with an estimated annual output of 12.046 million metric tons.

Brazil is the largest rice producer outside of Asia, with an estimated annual production of 12.046 million metric tons (Companhia Nacional de Abastecimento [CONAB], 2024), representing 1.2% of global production (Costa-Neto *et al.*, 2024). Rice cultivation in Brazil occurs in both subtropical (southern Brazil) and tropical (southeastern, central-western, northern, and northeastern Brazil) regions (Costa-Neto *et al.*, 2024). Like all crops, rice requires adequate nitrogen fertilization for optimal growth (Zhou et al., 2019; Zhu *et al.*, 2023). This macronutrient is available to plants as nitrate ($NO_3^-$) and ammonium ($NH_4^+$), though ammonium is preferentially absorbed (Du *et al.*, 2019). Nitrogen is crucial for plant metabolism, and both its deficiency and excess can induce physiological stress (Wang *et al.*, 2020).

Currently, ammonia emissions in many countries are increasing with the activities of agricultural systems, in particular the application of fertilizers, contributing to the high presence of ammonia in the atmosphere (Zhou *et al.,* 2022). Worldwide, an average of 18% of nitrogen fertilizer is lost through ammonia emissions (Yang *et al.*, 2019). The frequent use attributed to inadequate fertilization methods in agriculture causes large losses of nitrogen in the environment, in the environmental sphere, pollution triggers a series of environmental problems (Ding *et al.*, 2020), starting with soil degradation, water eutrophication, groundwater pollution, as well as contributing to the greenhouse effect (Zhang *et al.*, 2017).

A lack of nitrogen can restrict plant growth, while nitrogen excess can exacerbate the severity of blast disease (*Pyricularia grisea*), the primary disease affecting rice cultivation (Chung *et al.*, 2022). Both deficiency and excess can reduce productivity and grain quality (Barros *et al.*, 2024). Similarly, increased planting density can negatively impact plant competition, disrupting root development and competition for nutrients and light, thus affecting plant height, tiller quality, and grain production (Gong *et al.*, 2022). However, optimal rice productivity depends on more than just climate and input quality. The presence of blast disease throughout the growing season disrupts photosynthesis and photoassimilate accumulation, negatively impacting grain filling (Ishikawa *et al.*, 2022). While the literature frequently addresses rice blast concerning rice genetics (Silva Neto *et al.*, 2023), chemical weed control (Scheuermann & Nesi, 2021) and the effects of nitrogen fertilization on disease development (Esa *et al.*, 2023; Ogoshi *et al.*, 2020).

The complex interactions between nitrogen fertilization, planting density and the incidence of blast in irrigated rice areas warrant further investigation, in order to obtain adequate and balanced management for the development of the crop. Therefore, the aim of this research was to evaluate the behavioral characteristics of rice cultivars in terms of their susceptibility to blast severity when subjected to different nitrogen rates and sowing densities and to identify their production potential and grain qualities.

## MATERIAL AND METHODS

### *Experimental conditions*

The experiment was conducted in the field during the 2021-22 growing season at Cooperativa Agroindustrial Rio Formoso Ltda - Cooperformoso, located in the southwestern Araguaia River valley (12°00’07” S latitude and 49°40’05” W longitude), in the state of Tocantins (Figure 1). The site is situated at an altitude of 195 meters above sea level, with an average temperature of 24°C and an average annual rainfall of 1,600 mm.

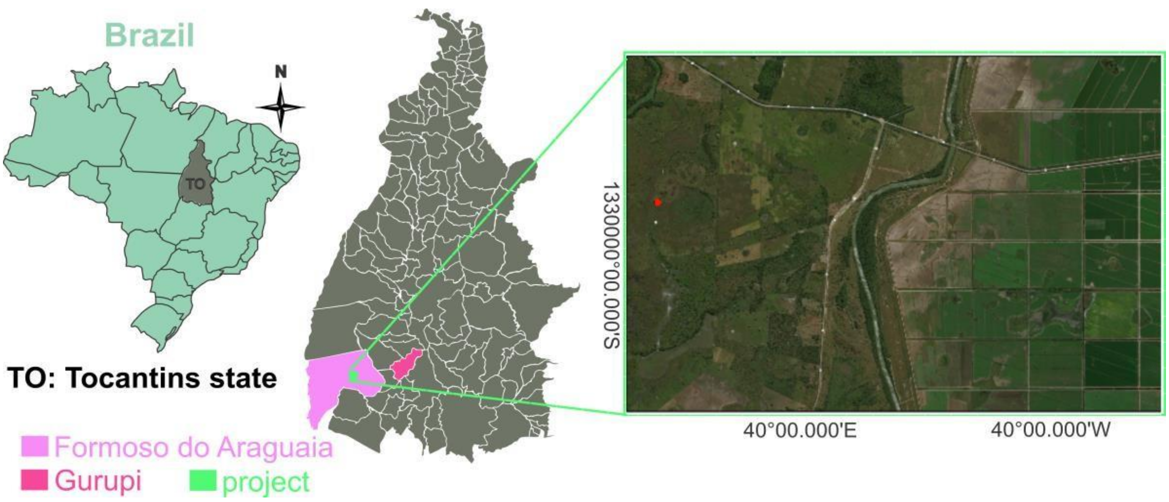


**Figure 1.** *Experimental area of CooperFormoso - TO and Federal University of Tocantins, Gurupi Campus - TO.*

Prior to sowing, soil samples were collected from the 0-10 cm, 10-20 cm, and 20-40 cm depths and subjected to physical and chemical analyses (Table 1). The soil was subsequently prepared using conventional methods, including plowing and harrowing. Rice seeds were treated with the insecticide Fipronil (40 g a.i. 100

kg seeds$^{-1}$) for preventive control of rootworm (*Oryzophagus oryzae*) and the fungicides Thiram and Carboxin (94 g a.i. 100 kg seeds$^{-1}$). These treated seeds were then sown at a depth of 3 cm. At sowing, a basal application of 230 kg ha$^{-1}$ of NPK (05-25-15) fertilizer was applied.

**Table 1**. *Chemical and physical evaluation of the soil in the Formoso do Araguaia experimental area – TO*

| Nutrient | Unit of measurement | Depth (cm) | | |
|---|---|---|---|---|
| | | **0 – 10** | **10 – 20** | **20 – 40** |
| Ca | | 3.1 | 2.7 | 3.4 |
| Mg | cmol/dm³ (mE/100ml) | 1.2 | 0.8 | 0.8 |
| K | | 0.14 | 0.03 | 0.05 |
| P(Melich) | | 25.4 | 24.0 | 17.0 |
| S | | 1.2 | 2.0 | 1.2 |
| Na | | 5.7 | 5.3 | 6.2 |
| Zn | mg/dm³ (ppm) | 3.8 | 3.2 | 5.7 |
| Cu | | 2.1 | 1.9 | 2.4 |
| Fe | | 183.1 | 155.3 | 135.0 |
| Mn | | 13.7 | 7.2 | 7.1 |
| Organica Matter | g/dm³ | 21.0 | 17.0 | 18.0 |
| $CaCl_2$ | pH | 5.3 | 5.9 | 5.9 |
| Clay | | 320 | 310 | 320 |
| Silt | (g/kg) | 90 | 80 | 90 |
| Sand | | 590 | 610 | 590 |

The experiment employed a randomized complete block design (RCBD) in a 5 x 4 x 2 factorial arrangement, comprising five nitrogen rates (urea, 45% N, applied as a top dressing) at 0 (control), 60, 100, 140, and 180 kg N ha$^{-1}$; four seeding rates (60, 90, 120, and 150 kg ha$^{-1}$); and two rice cultivars (BRS A704 and BRS A706 CL). Four replicates were used, resulting in a total of 160 plots, each measuring 3,4 m² and consisting of four 5-meter rows spaced 0,17 m apart. Weed, pest, and disease management followed standard regional practices (Santos *et al.*, 2002). Nitrogen was applied in two splits: 30% of the total amount per treatment at the vegetative stage (V3) and the remaining 70% at the reproductive stage (R0), following the recommendations of Counce *et al.* (2000). After each nitrogen application, a 15 mm flood was established to incorporate the nitrogen into the soil.

**Climate Variables in the experimental area:** Climatic conditions in the experimental area were monitored daily throughout the vegetative and reproductive growth stages. Data on rainfall (mm), maximum, minimum, and dew point temperatures (°C), and relative humidity (%) were collected from the Instituto Nacional de Meteorologia do Brasil (INMET, 2022). Monitoring occurred from November to December 2021 during the vegetative stage and from January to February 2022 during the reproductive stage.

**Evaluation of *Pyricularia grisea* (blast) progression under varying nitrogen rate and seed densities**

Blast disease (*Pyricularia grisea*) progression was assessed using the Area Under the Disease Progress Curve (AUDPC). Leaf blast was evaluated at the vegetative stage (V5) 30 days after emergence (DAE), and panicle blast was evaluated at the reproductive stage (R3), at panicle emergence. Weekly assessments, for a total of five evaluations at seven-day intervals, were conducted for both leaf and panicle blast. A 0-9 scale (using odd numbers), as recommended by the International Center for Tropical Agriculture (Rosero, 1983) and adapted by Santos *et al.* (2005), was used for disease scoring. Scores were converted to percentages (0-75%) and used to calculate the AUDPC according to Equation 1, as described by Shaner and Finney (1977).

$$AUDPC = \sum_{i=1}^{n-1} \frac{(YY_{i+1} + YY_{i}) * (T_{i+1} - T_{i})}{2} \quad (1)$$

Where:
AUDPC= Area under the disease progress curve;
Yi+1: disease severity at the time of evaluation;
Yi: disease severity at the time of the previous evaluation i=(i=1,...,n);
T: time of evaluation;
Ti+1: time of the previous evaluation i+1;
n: total number of evaluations;
i: number of days after seedling emergence.

***Evaluation of protein content in rice grain***

To determine the crude protein (CP) content of rice grains, ten panicles were collected from the two central rows of each plot prior to harvest. The collected panicles were dried in an oven at 105°C until a constant weight was achieved. Grains were then separated from the panicles and ground using a Willey-Solab knife mill with a 20-mesh sieve. Following grinding, 2-gram subsamples were taken for total nitrogen quantification. Nitrogen content was determined using acid digestion and distillation following the method described by Tedesco *et al.* (1995). Crude protein content was then calculated by multiplying the determined nitrogen content by a conversion factor of 6.25.

***Impact of nitrogen dose and seed density on rice productivity***

At the end of the growing cycle for both cultivars, harvest was performed manually at 130 days after sowing (DAS). Panicles were collected from the two central rows of each plot, covering an area of 1,36 m², using a sickle. A threshing machine was used to separate the grains from the panicles. The grain samples were then placed in cloth bags, packed, and dried in an oven until the grain moisture content reached approximately 13%, as measured by a grain moisture meter ( Brasil. Ministério da Agricultura, Pecuária e Abastecimento, 2009). After moisture determination, the thousand-grain weight and grain yield (kg ha$^{-1}$ at 13% moisture) for each sample were calculated using Equation 2.

$$Productivity\ (kg.ha^{-1}) = 7.352,94\ x\ weight\ of\ the\ area\ collected/1000 \quad (2)$$

### *Statistical analysis*

The data for each measured variable were initially analyzed using factorial analysis of variance (ANOVA) in SigmaPlot 12.5, with cultivar, nitrogen rate, and seeding rate as the main factors. Differences between the nitrogen doses in the same density seed was submitted to ANOVA parametric (normally distributed data), or the ANOVA non-parametric (non-normally distributed data) followed by the Dunn's post-hoc test (*P*< 0.05) using SAS 9.1.

## RESULTS

### *Climatic conditions*

During the AUDPC evaluations at the vegetative stage (November-December 2021), the total rainfall was 562 mm. Average maximum, minimum, and dew point temperatures were 26°C, 25°C, and 22°C, respectively, with a relative humidity of 81%. During the reproductive stage (January-February 2022), accumulated rainfall decreased to 397 mm, while average temperatures and relative humidity remained consistent with the vegetative stage.

### *Influence of nitrogen and sowing density on the Area Under the Disease Progress Curve (AUDPC) in cultivars BRS A704 and BRS A706 CL*

The Area Under the Disease Progress Curve (AUDPC) for rice blast was significantly influenced by cultivar, nitrogen rate, and seeding rate during both the vegetative and reproductive stages. However, significant interactions between cultivar and nitrogen rate, and between nitrogen rate and seeding rate, were observed only during the reproductive stage (Table 2).

**Table 2**. *Area Under the Disease Progress Curve (AUDPC) in the vegetative and reproductive stages of rice under different nitrogen rates and densities*

| Source of Variation | Vegetative stage df | MS | F | *P* | Reproductive stage df | MS | F | *P* |
|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | 1 | 13,861.125 | 8.66 | **0.0041*** | 1 | 21,658.007 | 16.58 | **<0.0001*** |
| Nitrogen (N) | 3 | 156,012.729 | 97.50 | **<0.0001*** | 3 | 301,266.091 | 230.63 | **<0.0001*** |
| Seed density (SD) | 3 | 15,871.270 | 9.92 | **<0.0001*** | 3 | 21,712.591 | 16.62 | **<0.0001*** |
| C x N | 3 | 1,280.437 | 0.80 | 0.4967 | 3 | 4,495.653 | 3.44 | **0.0198*** |
| C x SD | 3 | 362.604 | 0.23 | 0.8777 | 3 | 117.778 | 0.09 | 0.9653 |
| N x SD | 9 | 1,458.763 | 0.91 | 0.5185 | 9 | 2,935.070 | 2.25 | **0.0252*** |
| C x N x SD | 9 | 1,013.750 | 0.63 | 0.7658 | 9 | 165.035 | 0.13 | 0.9989 |
| **Residual** | 31 | 17,957.899 | 11.22 | **<0.0001** | 31 | 33,301.139 | 25.49 | **<0.0001*** |

*significance (P < 0.05)

The progression of blast in both the vegetative and reproductive phases showed high AUDPC values for both cultivars, as nitrogen rates and sowing density increased (Figure 2). The progression of leaf blight in the vegetative phase (Figure 2A-B) can be seen in the high AUDPC value of 130% when nitrogen rates were higher than 100 kg N ha$^{-1}$. These values increased even more, exceeding 200% at a dose of 180 kg N ha$^{-1}$ and sowing densities above 90 kg ha$^{-1}$.

During the reproductive stage (Figure 2C-D), panicle blast progression followed similar trends for both cultivars. However, BRS A706 CL (Figure 2C) exhibited AUDPC values ranging from 150% to 340% for nitrogen rates above 140 kg N ha$^{-1}$ and seeding densities greater than 90 kg ha$^{-1}$, suggesting greater resistance to panicle blast compared to BRS A704.

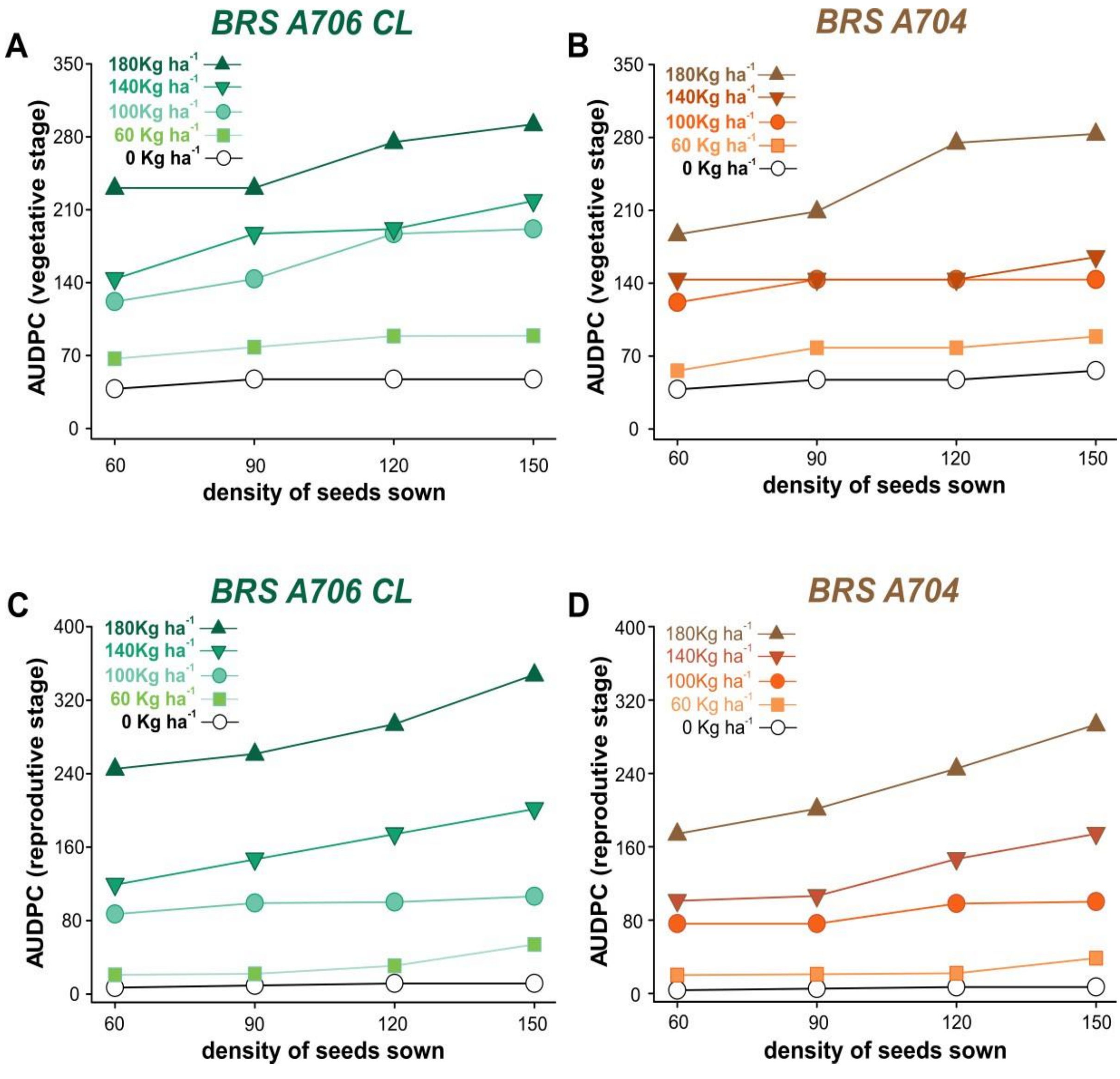


**Figure 2.** *Area Under the Disease Progress Curve (AUDPC) in the vegetative (A, B) and reproductive (C, D) stages in two rice varieties under different nitrogen rates and seed densities.*

### *Evaluation of protein content in rice grains*

The protein content in rice grains was influenced only by nitrogen and not by cultivars or seed density (Table 3). The results indicate no significant interaction between these factors.

**Table 3.** *Effect of cultivar, nitrogen rates and plant densities on the protein content of rice grains.*

| Source of Variation | DF | MS | F | *P* |
|---|---|---|---|---|
| Cultivar (C) | 1 | 1.306 | 1.538 | 0.218 |
| Nitrogen (N) | 3 | 2.371 | 2.793 | **0.044*** |
| Seeds Density (SD) | 3 | 0.942 | 1.110 | 0.349 |
| C x N | 3 | 1.160 | 1.366 | 0.258 |
| C x SD | 3 | 0.819 | 0.964 | 0.413 |
| N x SD | 9 | 0.962 | 1.134 | 0.347 |
| C x N x SD | 9 | 0.942 | 1.110 | 0.363 |
| **Residual** | **96** | **96** | | |

*significance ($P < 0.05$)

Regardless of cultivar, rice grains from treatments receiving higher nitrogen rates exhibited the highest protein content. Both cultivars achieved an average protein content of 8% at the highest top-dressed nitrogen rate (Figure 3). In BRS A706 CL (Figure 3A), no significant variation in protein content was observed between the 140 kg N ha-1 treatment and the control, with average protein content ranging from 3.5% to 5%. Conversely, BRS A704 (Figure 3B) showed the greatest variation in average protein content among treatments at the lowest seeding density (SD). As seeding density increased, this variation decreased, with protein values ranging from 3.5% to 5% (Figure 3B).

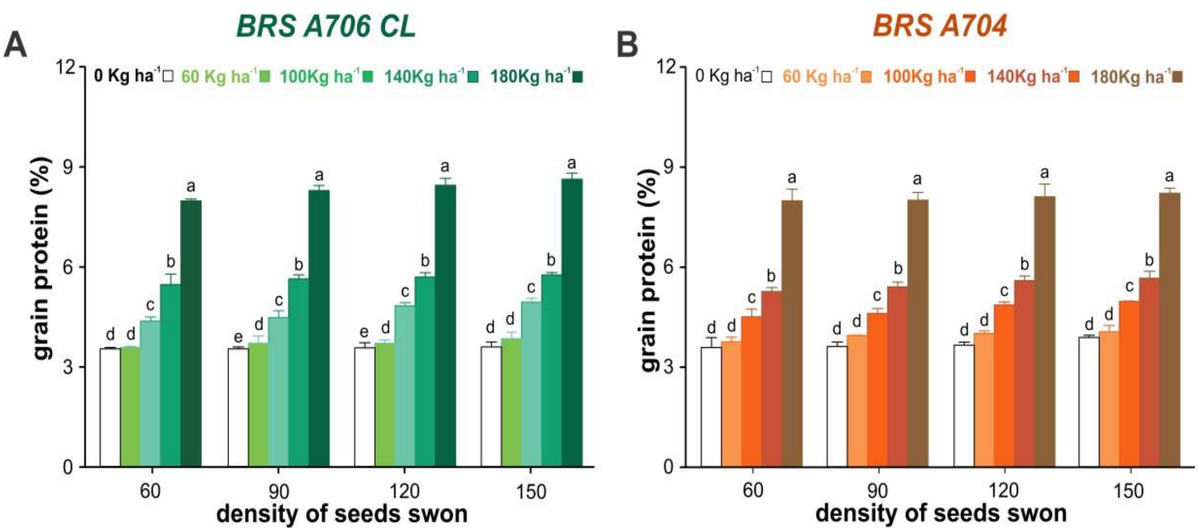


**Figure 3.** *Effect of nitrogen on the protein content in the grains of the rice cultivars BRS A706 CL (A) and BRS A704 (B), when planted in different seed densities. Bars showed the mean (±SE), and equal letters over these in a same density of seed significate difference statistic by the Dunn's post-hoc test (P< 0.05).*

### *Impact of nitrogen dose and seed density on rice productivity*

Rice yield was influenced by cultivar, nitrogen dose, and seed density; with a significant interaction observed between cultivar and nitrogen dose (Table 4).

**Table 4.** *Effect of nitrogen and plant density on irrigated rice productivity*

| Source of Variation | DF | MS | F | *P* |
|---|---|---|---|---|
| Cultivar (C) | 1 | 1,483,933.78 | 5.88 | **0.0172*** |
| Nitrogen (N) | 3 | 29,836,714.78 | 118.23 | **<0.0001*** |
| Seeds Density (SD) | 3 | 1,238,895.43 | 4.91 | **0.0032*** |
| C x N | 3 | 1,368,624.28 | 5.42 | **0.0017*** |
| C x SD | 3 | 51,126.18 | 0.20 | 0.8944 |
| N x SD | 9 | 117,060.70 | 0.46 | 0.8954 |
| C x N x SD | 9 | 121,922.40 | 0.48 | 0.8827 |
| **Residual** | **96** | 3,261,963.3 | 12.93 | **<0.0001** |

*significance ($P < 0.05$)

Rice yields were highest at a nitrogen rate of 140 kg N ha-1 for both cultivars (Figure 4 A-B). BRS A706 CL (Figure 4A) performed best at nitrogen rates of 140 kg N ha-1 and 100 kg N ha-1, with seeding densities above 90 kg ha-1, achieving average yields of 6,580 kg ha-1 and 5,598 kg ha-1, respectively. BRS A704 (Figure 4B) achieved higher productivity with an average yield of 6,595 kg ha-1 at 140 kg N ha-1 and 5,908 kg ha-1 at 180 kg N ha-1 at all sowing densities.

In terms of yield variations, the two cultivars behaved differently. The BRS 706 CL cultivar, when planted at a rate of 0 kg N ha-1 and at different sowing densities, obtained a yield below 3,500 kg ha-1, while at rates above 60 kg N ha-1 the results were above 4,500 kg ha-1, regardless of sowing density. On the other hand, BRS A704 showed variations in productivity at rates of 0 and 60 kg N ha-1 when sown at a density of 150 kg ha-1. These variations in rice productivity are probably related to the AUDPC of blast throughout the crop cycle.

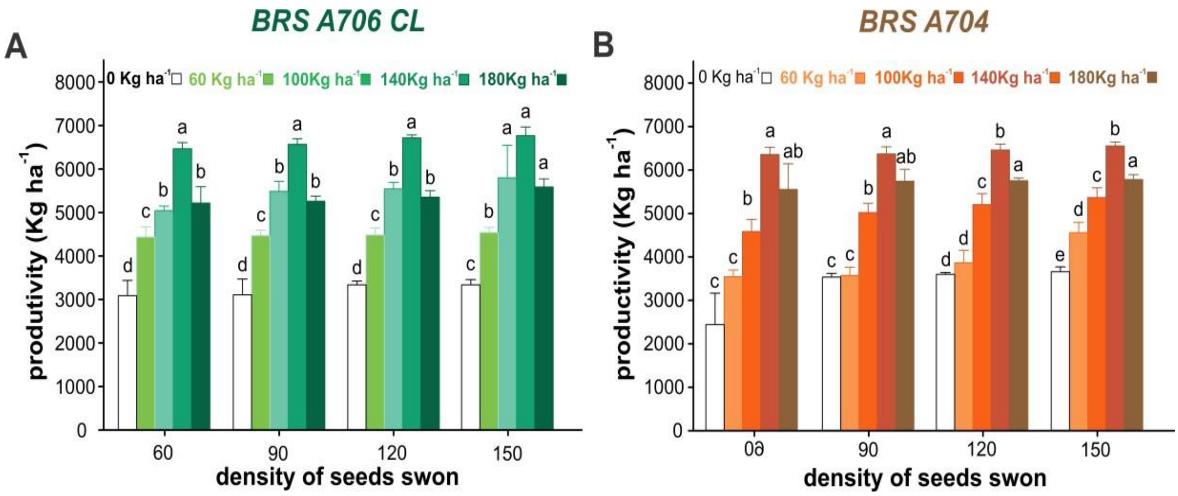


**Figure 4.** *Effect of nitrogen on the productivity of the rice cultivars BRS A706 CL (A) and BRS A704 (B), when planted in different seed densities. Bars showed the mean (±SE), and equal letters over these in a same density of seed significate difference statistic by the Dunn's post-hoc test (P< 0.05).*

## DISCUSSIONS

Our results indicate that high nitrogen rates, high seeding densities, and elevated temperature and humidity created a conducive microclimate for blast development and spread throughout the rice growing cycle. Furthermore, the presence of red rice intensified competition for resources, hindering rice growth and potentially exacerbating blast incidence, as red rice can be highly susceptible to pathogens. Consequently, rice yields were reduced due to blast pressure and competition between the rice cultivars and red rice.

The observed climatic conditions remained relatively consistent throughout the experiment, with the exception of decreased rainfall during the reproductive stage. Climate change can exacerbate the development and severity of major rice diseases (Gautam *et al.*, 2013). Factors critical for blast development include the number of rainy days, temperatures between 16 and 28°C, and relative humidity above 80% for at least nine consecutive hours (Singh *et al.*, 2019). Rain splash also contributes to the dispersal of disease spores (Gilet & Bourouiba, 2015). Additionally, temperature, $CO_2$ concentration, relative humidity, and sunlight can directly influence stomatal behavior (Toh *et al.*, 2021).

Blast is considered the most devastating disease affecting rice cultivation (Ng et al., 2020), followed by sheath blight, caused by *Rhizoctonia solani* (Timsina *et al.*, 2022). Infection by these phytopathogens is influenced by susceptible cultivars, pathogen virulence, and environmental conditions conducive to fungal development and disease severity (Singh *et al.*, 2019). High plant density can also create a microclimate with altered air temperature and humidity, favoring fungal growth. Increased nitrogen rates can exacerbate blast severity throughout the rice growing cycle (Bregaglio *et al.*, 2017) and contribute to sheath blight development (Prasad *et al.*, 2020).

The application of nitrogen at a dose of 170 N kg ha$^{-1,}$ at 120 kg ha-1 sowing density in three different seasons: 2022, 2023 and 2024, allowed the incidence of blast in all rice cultivars, especially in the first two years (Rodríguez Pedroso *et al.*, 2025), so our results are similar to those of this study, since the dose of nitrogen and the sowing density are close to the values used, corresponding to 180 kg ha-1 and 150 kg ha-1 respectively, allowing for greater progression of the disease, regardless of the cultivars.

Low temperatures and frequent rainfall are critical for panicle blast development (Oliveira *et al.*, 2019). High nitrogen rates can induce physiological imbalances in plants, reducing the synthesis of phenolic compounds such as phytoalexins and lignin, which can increase susceptibility to fungal infection (Marschner *et al.*, 2002). This disruption of plant growth and metabolic processes facilitates fungal colonization on leaf surfaces (Oliveira *et al.*, 2019).

Grain crude protein content increased with increasing nitrogen application. Grains with lower protein and starch content tend to be more opaque and exhibit reduced grain strength (Sofiatti et al., 2006). The higher protein content observed with increased nitrogen is likely due to greater photoassimilate production during grain filling (Silva *et al.*, 2013). Conversely, lower rates of top-dressed nitrogen resulted in reduced grain protein content, possibly due to high temperatures during the initial grain-filling period, leading to decreased nitrogen accumulation and consequently, lower amino acid content (Huang *et al.*, 2019).

These findings are consistent with those of Dawood *et al.* (2023), who reported that nitrogen fertilization with urea significantly increased grain protein content. Higher nitrogen rates also resulted in increased yields, with BRS A706 CL demonstrating the highest yield potential at 8,798 kg ha-¹ (Rangel *et al.*, 2022). BRS A704 achieved an average yield of 7,835 kg ha-¹ (Colombari Filho *et al.*, 2019), representing a reduction of over 2,000 kg between treatments.

In a study carried out in Roraima, with the BRS 358 cultivar in a flooded area, the rate of 209 kg N ha-1, determined maximum productivity efficiency with 6,245 kg.ha-1, but the highest dose applied of 300 kg N ha-1, there was a drop in rice productivity (Pereira *et al.*, 2020). Based on these results, the nitrogen rate of 140 kg N ha-1 N in this study enabled rice grain yields of over 6,000 kg.ha-¹, a result close to that of the aforementioned author, but with the advantage of using less nitrogen.

According to Faria *et al.* (2020), working with the BRS Primavera and BRS Sertaneja cultivars under varying nitrogen rates (0, 80, and 240 kg N/ha), found that nitrogen fertilization improved grain quality without affecting productivity. Nitrogen is widely recognized as the primary limiting factor for rice productivity. As noted by Kato *et al.* (2023), grain quality is determined early in development, starting with carbon fixation during photosynthesis and subsequent translocation of sucrose from leaves to the panicle, spikelets, and developing grains. The carbon transported to the grain tends to be more enriched than that stored in the leaves due to the activity of enzymes involved in sucrose metabolism, such as beta-fructofuranosidase (Bögelein *et al.*, 2019).

Rice texture, a key aspect of grain quality, is determined by the internal grain structure, including attributes such as hardness and stickiness (von Borries *et al.*, 2018). Poor grain quality, often associated with blast incidence, directly impacts the average yield of irrigated rice. Severe blast infestations can cause yield losses of up to 100% (Bregaglio *et al.*, 2017), especially in susceptible cultivars. Red rice (*Oryza sativa* L.) infestation is another factor that can significantly reduce productivity. Furthermore, the presence of red rice can exacerbate blast severity, as red rice is also susceptible to the disease.

Red rice, with its early emergence and adventitious rooting system, efficiently absorbs nitrogen and exhibits traits such as high stomatal conductance, enabling it to effectively compete with cultivated rice (Agostinetto *et al.*, 2018). Studies have shown that applying nitrogen rates above recommended levels can induce oxidative stress. Affecting the cytosolic ascorbate peroxidase gene (OsAPX2) due to nitrogen excess (Agrawal et al., 2003; Hong et al., 2018). This type of stress has been observed in other crops, including wheat (Abdisa Jalata *et al.*, 2022), maize (Bationo *et al.*, 2012), and sorghum (Pereira et al., 2014), where it resulted in reduced productivity due to weed competition. While transplanting can be an effective method for red rice control (Imaizumi, 2018), direct seeding is more common. Red rice can be controlled using herbicides such as Kifix and Only, but this requires Clearfield (CL) cultivars, like BRS A706 CL, which carries a resistance gene to imidazolinone (IMI) herbicides (Rangel *et al.*, 2022). BRS A704, a non-CL cultivar, did not receive Kifix or Only treatment. However, it demonstrated good resistance to blast and performed well under higher nitrogen rates (Colombari Filho *et al.*, 2019).

## CONCLUSIONS

Climatic conditions, combined with high nitrogen rates and sowing density, contributed to the increase in AUDPC in both cultivars. Therefore, although these rice cultivars are indicated for resistance to blast, nitrogen rates above 140 kg N ha$^{-1}$ and sowing density greater than 90 kg.ha-1 influenced the progress of the disease. However, productivity increased between rates of 60 and 140 kg N ha-1, reaching yields of over 4,500 and 6,500 kg ha-1 for both cultivars. However, there was a loss of productivity for the 180 kg N ha-1 rate and this behavior may be related to the incidence and progress of blast. It is therefore necessary to use management strategies in the application of nitrogen, as well as in seed distribution, in line with the development of new resistant cultivars through breeding programs.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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