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Agronomic performance of the rice cultivar Tumbeta as a function of plant density

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Abstract

Adjustments in the planting density of the Tumbeta variety under an irrigated system directly influence vegetative growth, resource use efficiency, and rice productivity. Defining an appropriate density maximizes crop yield. This work was developed to evaluate the effect of plant density on the agronomic performance of the Tumbeta rice cultivar under an irrigation system. The experiment was carried out during the 2022/2023 season at the Chókwè Agricultural Station, Gaza province, Mozambique, using a randomized complete block design (RCBD), with ten treatments and three replications, totaling 30 plots. The treatments used were different transplant densities. The transplant densities ranged from 1 to 10 seedlings per hole. The variables analyzed were grain yield and number of panicles m^{-2}. The analysis of variance (ANOVA) revealed a significant effect of plant density on grain yield and the number of panicles m^{-2}. The highest grain yields were observed at densities of 4, 5, 6, and 7 plants per hole, with averages of 9.7, 9.4, 9, and 9 t ha^{-1}, respectively. For the number of panicles m^{-2}, the best density was 4 plants per hole, with 379 panicles m^{-2}. It is important to highlight that the plant density per hole has a direct impact on grain yield and the number of panicles m^{-2} of the Tumbeta rice cultivar.

Keywords: *Oryza sativa* L. Panicles. Grain Yield. Flooded Rice.

Introduction

Rice (*Oryza sativa* L.) is one of the most widely cultivated cereals in the world and constitutes the staple food for more than half of the global population, particularly in countries in Asia, Africa, and Latin America (GARCIA *et al*., 2024). In addition to its nutritional role, this crop is crucial for food security and the socioeconomic development of producing regions (FAO *et al*., 2022). In a context of increasing food demand and the need for greater production efficiency, optimizing management practices, such as planting density, becomes essential to ensure high yields and the sustainability of production.

Planting density is a determining factor for the growth, development, and productivity of rice. This parameter directly influences the number of tillers produced, light interception efficiency, nutrient absorption, and water use (FAGERIA, 2014). Establishing an adequate density maximizes the use of natural resources, minimizes intraspecific competition, and contributes to the sustainability of the crop (KUMAR *et al*., 2021).

The Tumbeta variety has high productive potential and adaptability to the climatic conditions of Mozambique (IIAM, 2022). However, there is a knowledge gap regarding the impact of planting density on its agronomic performance under an irrigated system. Proper adjustments in this parameter may directly affect vegetative growth, resistance to pests and diseases, as well as optimize water and soil nutrient use (PENG *et al*., 2021).

The relationship between planting density and plant architecture is crucial for efficient crop management. Excessive densities can intensify competition for light and nutrients, reducing the number of productive tillers and increasing susceptibility to diseases due to reduced canopy ventilation (YANG *et al*., 2021). On the other hand, very low densities favor the growth of weeds and result in lower productivity per hectare (CHOUDHARY *et al*., 2022).

In addition, planting density influences the quality of the harvested grains, as changes in plant structure impact grain filling and uniformity. Crops with excessive density may result in smaller and lighter grains, while excessively wide spacings may compromise total grain productivity (DAS *et al*., 2018). Proper adjustment of this factor is essential to optimize harvest and maximize yields for producers.

In light of the above, this study was developed to evaluate the impact of different planting densities on the agronomic performance of the Tumbeta variety under an irrigated system, contributing to the improvement of management strategies and the sustainability of rice production in Mozambique.

Materials and methods

The experiment was carried out during the 2022/2023 growing season in the municipality of Chókwè, located in the southern region of Gaza Province, Mozambique, at the Chókwè Agricultural Station, covering an area of 306.25 m^2 (24°32'1.20" S, 33°1'0.02" E). The climate is classified as semi-arid, with annual precipitation ranging from 500 to 800 mm and an average temperature between 22°C and 26°C. The soil is deep, clayey, and highly fertile (MOÇAMBIQUE, 2020).

Randomized complete block design (RCBD) was adopted with 10 treatments and three replications, totaling 30 plots. The treatments consisted of different transplanting densities: T1 - one seedling per hole T2 - two seedlings per hole; T3 - three seedlings per hole; T4 - four seedlings per hole; T5 - five seedlings per hole; T6 - six seedlings per hole; T7 - seven seedlings per hole; T8 - eight seedlings per hole; T9 - nine seedlings per hole; and T10 - ten seedlings per hole. The flooded rice cultivar "Tumbeta" was used, characterized as an early-maturing variety with a growth cycle of 90 to 100 days. The experimental plots measured 5 m in length and 1.2 m in width. The border between plots was 0.5 m, and the spacing between blocks was 1.25 m. The spacing between plants and rows was 20 cm.

Soil preparation was carried out mechanically, including plowing to a depth of 0.20 m and two harrowings at 0.15 m. During the second harrowing, fertilizer NPK (12-24-12) was incorporated at a rate of 90 kg ha^{-1}. Subsequently, the soil was fractioned, flooded, and leveled. The division and leveling of the plots were performed under dry soil conditions using hoes and rakes, followed by the first irrigation. The seedlings, with 3 to 5 leaves, were removed from the nursery in a greenhouse and transplanted to the experimental site.

Evaluated characteristics

The following agronomic characteristics were evaluated:

i. Number of panicles m^{-2}: determined by counting the panicles within a 1 m^2 sample and calculating the average number.

ii. Grain yield: determined by the weight of grains from the net plot area after harvest and drying to 13 % moisture content.

Statistical analysis

The data were analyzed using the R statistical computing environment (R CORE TEAM, 2024). The assumptions of residual normality were verified (SHAPIRO, WILK, 1965), independence of errors (DURBIN, WATSON, 1950) and homoscedasticity (BARTLETT, 1937). When these assumptions were met, analysis of variance (ANOVA) was performed. For mean grouping, the Scott-Knott test (1974) was used at a 5 % significance level for significant variables. To analyze the relationship between a dependent variable and an independent variable, the linear regression method was used. Additionally, the coefficient of variation (CV%) was calculated to assess the relative dispersion of the data.

Results and discussion

Significant influence of plant density per hole was found on the grain yield and on the number of panicles per square meter for the flooded rice cultivar Tumbeta (Table 1).

The analysis of variance confirmed that plant density had a statistically significant effect on both variables, highlighting its relevance as a key factor in crop management to maximize productivity. The coefficients of variation obtained for grain yield and the number of panicles were below 10 %, indicating high experimental precision. According to Gomes (2023), CV% values below this threshold indicate low variability among replications and high reliability of the data obtained. This reinforces the statistical validity of the inferences made and the applicability of the results for agricultural management recommendations, especially in rice cultivation.

Analyzing the grain yield variable, it can be inferred that the mean values obtained for this characteristic varied according to the seedling density per hole (Figure 1a).

The highest grain yields were observed at densities of 4, 5, 6, and 7 seedlings per hole, with averages of 9.7, 9.4, 9, and 9 t ha-^{1}, respectively. In contrast, densities of 1, 2, 3, 8, 9, and 10 seedlings per hole resulted in lower yields, ranging from 5 to 8.7 t ha-^{1}. The results suggest that both underutilization of space and excessive competition among plants may compromise crop yield (Figure 1a).

In previous studies, it was shown that moderate planting densities promote the efficient use of resources such as light, water, and nutrients, reducing intraspecific competition

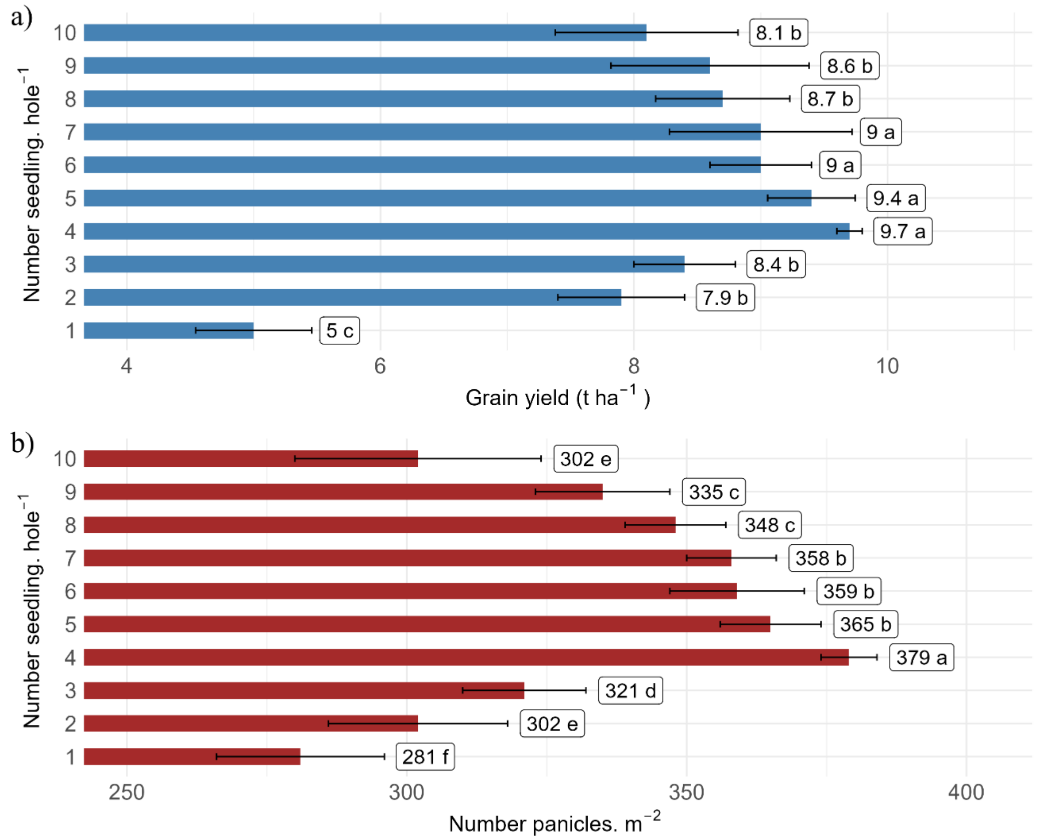
Table 1. Summary of the analysis of variance regarding grain yield and number of panicles m-^{2} of the flooded rice cultivar Tumbeta subjected to different plant densities per hole in the 2022/23 season, in Mozambique, Gaza province, Chokwe district.

Source of Variation	DF	**Mean Square**	
		Grain yield (t ha-^{1})	Panicles m-^{2}
Seedlings per hole	9	5,14	3.133,33
Block	2	0,22	902,50
Residual	18	-	-
		p-valor	
Seedlings per hole	9	3,38x10^{-7}*	5,38x10^{-10}*
Block	2	0,49^{ns}	6,78x10^{-4}*
CV (%)	-	6,44	2,67

DF: Degrees of freedom. *Significant by the F test, $p < 0.05$; ^{ns}: not significant by the F test, $p < 0.05$.

Source: authors (2025).

Figure 1. Grain yield and number of panicles m-² as a function of the number of seedlings per hole of the flooded rice cultivar Tumbeta in the 2022/23 season, in Mozambique, Gaza province, Chokwe district.



Means followed by the same lowercase letter do not differ significantly from each other according to the Scott and Knott test (1974), $p < 0.05$.

Source: authors (2025).

(ZHENG *et al*., 2020). On the other hand, in the present study, densities greater than 7 seedlings per hole resulted in reduced grain yield, possibly due to increased competition for essential resources, which may have impaired photosynthetic capacity and grain development (PENG *et al*., 2021).

This effect might be explained by the relationship between plant density and canopy closure, which, up to a certain point, improves light interception, optimizing photosynthesis and increasing accumulated biomass. However, when density exceeds a critical threshold, intense intraspecific competition reduces carbon assimilation and impairs grain formation (YOSHIDA, 1981; SOUSA *et al*., 2021).

The importance of plant density in rice productivity was also demonstrated by Singh *et al*. (2022), who observed that reducing plant spacing improves the leaf area index and the efficiency of converting photoassimilates into productive biomass. However, overcrowding can limit root growth, restricting water and nutrient uptake, which may explain the decrease in productivity at densities above 7 seedlings per hole in the present study. Additionally, densities below 4 seedlings per hole resulted in reduced productivity (5 to 8.7 t ha-¹), which can be attributed to the underutilization of available space and low solar radiation interception. This relationship confirms that insufficient plant density can lead to lower efficiency in the conversion of biomass into grains (XIE *et al*., 2019).

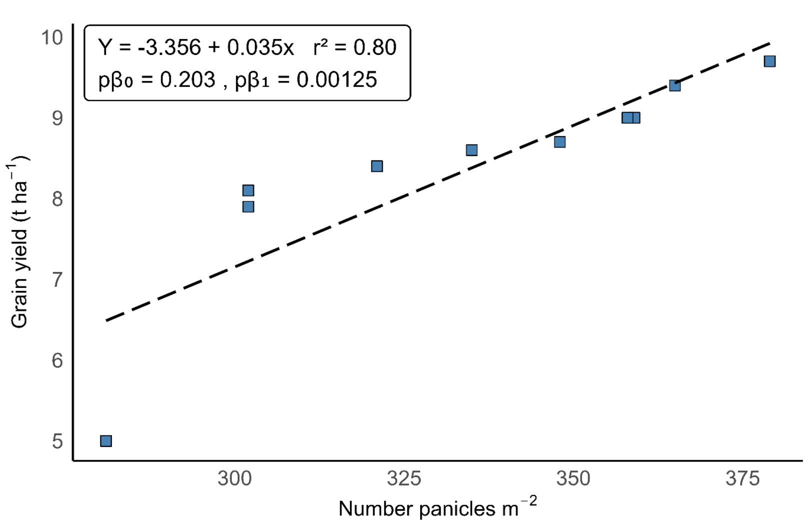
Regarding the variable number of panicles per square meter, there was also variation as a function of plant density per hole (Figure 1b). This highlights the existence of an optimal density point that maximizes the reproductive development of the crop. Therefore, the highest mean number of panicles per square meter was observed at a density of 4 seedlings per hole, with 379 panicles m^{-2}. Both lower and higher densities, especially 1, 2, 3, and 10 seedlings per hole, resulted in significantly lower values, with 281, 302, 321, and 302 panicles m^{-2}, respectively. These results highlight the impact of plant density on panicle formation, indicating that both excessive increases and reductions in density can compromise the productivity of the Tumbeta cultivar.

The number of panicles per unit area is one of the main components of rice yield. (FAGERIA, 2014). Very low densities result in a lower number of productive tillers per area, while high densities can reduce the production of reproductive tillers due to competition among plants for resources (SOUSA *et al*., 2021). Khush (2013) demonstrated that, at high densities, competition for light and nutrients affects the differentiation of meristems into panicles, limiting the production of productive tillers.

The relationship between grain yield and the number of panicles per square meter was adjusted to a significant linear fit (Figure 2).

This relationship has been reported in recent studies conducted by Yao *et al*. (2023) and Kim *et al*. (2024), which highlighted that the ideal seedling density allows for an optimal balance between tillering and grain production, avoiding the negative effects of excessive competition. Thus, an increase in the number of panicles was accompanied by a rise in productivity, which is consistent with the eco-physiological principles of rice (YOSHIDA, 1981).

Figure 2. Relationship between grain yield and the number of panicles m^{-2} of the flooded rice cultivar Tumbeta in the 2022/23 season, in Mozambique, Gaza province, Chokwe district.



*Significant by the F test, $p < 0.05$ for linear regression. Observed Data (Blue Squares): each blue dot represents the grain yield obtained, where the x-coordinate is the number of panicles and the y-coordinate is the yield. Regression Line (Black Line): the black line represents the best linear approximation of the observed data through ANOVA.

Source: authors (2025).

The linear regression obtained reinforces that panicle formation is a determining factor for the final grain yield. According to Murata e Matsushima (1975), rice grain yield is associated with the number of panicles per unit area and the ability of these panicles to produce viable grains. Thus, management strategies that promote the ideal plant density can directly contribute to increasing productivity, maximizing the genetic potential of the Tumbeta cultivar.

The data obtained in this study have direct implications for the management of rice in flooded rice production systems. The definition of the ideal plant density is crucial to prevent productivity losses resulting from plant scarcity or excessive competition. In addition, these results can be applied in breeding programs. Understanding the relationship between plant density and grain production can assist in the selection of more efficient genotypes under different spatial arrangements. As pointed out by Khush (2013), the modernization of rice cultivation should consider not only genetic traits but also the interaction of these traits with agronomic management to optimize crop yield.

Conclusion

The ideal density, between 4 and 7 seedlings per hole, confirms the hypothesis that planting density influences the agronomic performance of the Tumbeta rice cultivar. Within this range, the crop achieved its highest grain yield and number of panicles, demonstrating that both very low and very high densities reduce productivity.

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