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CROP PRODUCTION

High-density planting effects on maxixe production

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ABSTRACT. Maxixe is a vegetable with high nutritional value, yet there is limited information on crop management practices, particularly regarding row and plant spacing. This study aimed to evaluate maxixe production under high planting densities in two locations, Montes Claros and Mocambinho, Minas Gerais State, Brazil. The experiment was designed as a 2 x 2 x 4 factorial scheme, with two locations, four plant numbers per hole, and four hole densities, using the cultivar Maxixe do Norte. A randomized block design with four replications was employed. The variables analyzed included the number of fruits per plant and per hectare, pericarp thickness, fresh and dry fruit mass, and overall productivity. Data were subjected to multiple regression analysis, and curve comparisons were made using the model identity test. No significant difference was observed in fruit yield between the two locations; the highest yield recorded was 56,489.63 kg ha^{-1} at the highest planting densities. Increased planting density resulted in higher yields in weight and number of fruits per area, but fewer fruits per plant and reduced fresh and dry fruit mass at higher densities. Therefore, considering production per area and plant, an intermediate planting density is most appropriate, as it enhances yield without compromising fruit quality. In short, the recommended density for optimal fruit production is 33,000 holes per hectare, with three plants per hole.

Keyword: *Cucumis anguria* L.; multiple regression analysis; planting spacing.

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Introduction

Maxixe (*Cucumis anguria* L.) is an unconventional vegetable of African origin and is a significant species within the *Cucumis* genus of the Cucurbitaceae family. Introduced to Brazil by enslaved Africans, it has since become well-established, particularly in the North and Northeast regions, as well as in northern Minas Gerais, Rio de Janeiro, and São Paulo (Reyes et al., 2022). Maxixe fruit promotes the proper functioning of body tissues and helps combat free radicals. Studies have highlighted its potential in preventing chronic diseases (Mendes et al., 2022), spurring research into its cultivation. Moreover, understanding and advancing maxixe cultivation can contribute to diversifying agricultural production, improving food security, and offering economic benefits to small farmers by meeting the growing demand for this health-promoting vegetable.

As a tropical plant, maxixe is highly adaptable to regions above 20°C (Reis et al., 2013). However, a huge portion of maxixe is still produced under low-cost conditions without specific cultivation practices, leading to low yields. While genetic improvement of maxixe, along with protected cultivation technology, has shown enormous potential for increasing productivity, there remains limited information regarding the development and genetic variability of maxixe populations and cultivated genotypes. Nonetheless, it is known that genetic improvement can yield significant gains in traits such as fruit diameter, length, and productivity (Reyes et al., 2022). Another approach to enhancing maxixe yield is through irrigated cultivation with appropriate plant spacing and the optimal number of plants per hole. However, there is limited information on this plant under such conditions, particularly concerning plant density per area.

Planting densification, which involves cultivating plants at high density, maximizes productivity by enabling greater production per area (Zhang et al., 2021). This practice optimizes space utilization, reduces weed presence, and improves soil conservation. Additionally, it promotes more efficient moisture retention and creates a more stable microclimate, shielding plants from adverse weather conditions and enhancing crop yields.

To achieve optimal productivity, it is crucial to determine the spacing that promotes the best plant density, thereby avoiding intraspecific competition and maximizing area utilization. The technique of superdense planting, aimed at maximizing production per area, has been applied to various vegetable crops, including rice (Saju & Thavaprakaash, 2020), mango (Dalvi et al., 2010), basil (Maboko & Plooy, 2013), sweet pepper (Silva et al., 2021), and onions intercropped with fava beans (Sheha et al., 2022). In northern Minas Gerais, maxixe seed producers have employed this technique; however, there is no literature documenting its effect on fruit yield and quality in the region. Studying planting density is crucial in agriculture. By determining the optimal spacing between plants within a given area, farmers can optimize resource utilization, achieve higher yields, and promote healthier crop growth.

Based on the above, this study aimed to evaluate the yield of irrigated maxixe as a function of high planting density in two production sites in northern Minas Gerais State, Brazil.

Material and methods

The experiment was conducted from April to September 2016 in Montes Claros, Minas Gerais State, Brazil (coordinates: 16°40′58.16″ S, 43°50′20.15″ W) and Mocambinho, Minas Gerais State, Brazil (Jaíba) (coordinates: 15°51'4" S, 43°3'53" W).

The treatments followed a 4 x 4 factorial design, comprising four different plant densities per hole (3, 5, 10, and 20 plants) and four densities of holes per hectare (13,330; 20,000; 50,000; and 66,660 holes), which corresponded to spacings of 1.50 x 0.50, 1.00 x 0.50, 0.80 x 0.25, and 0.60 x 0.25 m, respectively. The cultivar Maxixe do Norte was used. A randomized block design with four replications was implemented, totaling sixty-four plots. Each plot consisted of 12 holes, with the number of plants per hole according to the treatment. The useful area consisted of two central holes.

Planting was done manually. Fertilizer was applied to the holes based on the spacing and the expected number of plants, following the crop's nutritional needs as determined by soil analysis (Table 1), using recommendations for cultivating cucurbits as a reference (Filgueira, 2008). Both sites were irrigated by micro-sprinklers, applying 30-35 mm of water twice to three times a week.

Table 1. Physical and chemical properties of the soil in experimental areas in Montes Claros and Mocambinho. Montes Claros, UFMG-Montes Claros, 2020.

Description	Municipalities	
	Mocambinho	Montes Claros
pH (H_2O)	6.80	7.0 A
P remaining	44.30	26.71
K (mg dm^{-3})	51	213
Mg ($cmol_c$ dm^{-3})	0.90	2.95
Al ($cmol_c$ dm^{-3})	0.00	0.00
H+Al ($cmol_c$ dm^{-3})	1.86	0.95
SB ($cmol_c$ dm^{-3})	3.03	9.25
t ($cmol_c$ dm^{-3})	3.03	9.25
m (%)	0.00	0.00
T ($cmol_c$ dm^{-3})	4.89	10.20
V (%)	62	91
Organic matter (dag kg^{-1})	2.50	3.71
Organic carbon (dag kg^{-1})	1.45	2.15
Coarse sand (dag kg^{-1})	86.10	14.30
Thin sand (dag kg^{-1})	3.90	17.70
Silt (dag kg^{-1})	4.00	36.00
Clay (dag kg^{-1})	6.00	36.00
Texture	Sandy	Average

The variables analyzed comprised the number of fruits per plant (NFP), pericarp thickness (PT), fresh fruit mass (FFM), dry fruit mass (DFM), number of fruits per hectare (NFH), and fruit yield (FY). NFP was determined by counting the fruits from the plot's useful area and dividing this by the number of plants from which they were harvested. PT was measured by cross-sectioning the fruits from the plot's useful area and measuring the pericarp thickness in millimeters using a caliper. FFM was measured by weighing 10 fruits in grams on a precision scale. These same fruits were then placed in a forced-circulation oven at 65°C for 72 hours to determine DFM in grams. NFH was calculated by multiplying the number of fruits per plant by the number of plants per hectare. FY was extrapolated by scaling the fruit mass from the plot's useful area to one hectare and expressed as kg ha^{-1}.

Data were subjected to multiple regression analysis using the least squares method, and the curves were compared using the model identity test. Statistical analyses were performed with the aid of the R software (R Core Team, 2022).

Results

The model identity test detected significant differences between the two sites evaluated (p-value < 0.01) for the variables NFP, PT, FFM, and DFM (Table 2). High determination coefficient values (R2) were observed.

Table 2. Model identity test and equations of the variables analyzed.

Model identity test							
Model	SV	NFP	PT	FFM	DFM	NFH	FY
C	m	4.15E+01	3.63E+01	3.34E+05	2.47E+03	2.22E+12	1.68E+09
	r	8.37E-01	7.26E-02	7.35E+02	4.84E+00	2.32E+10	3.80E+07
R	3	7.87E+01	7.07E+01	6.52E+05	4.66E+03	4.42E+12	3.29E+09
	4	1.61E+00	4.87E-01	4.29E+03	6.68E+01	2.27E+10	4.45E+07
IM	F	50,195	2,574,337	2,196,778	5,647,218	0.92	1.73
	p	0	0	0	0	0.5	0.16

Munc.	Var.	Equation	R^2
MB	NFP	$Y=4.92^{**}+0.70^{NS}X+0.10^{NS}X^2-0.41^{**}Z+0.01^{NS}Z^2+0.002^{NS}XZ$	36.92
	PT	$Y=2.16^{**}+0.64^{NS}X-0.08^{NS}X^2-0.01^{**}Z+0.00^{NS}Z^2+0.001^{NS}XZ$	83.78
	FFM	$Y=286.42^{**}+20.03^{NS}X-3.22^{NS}X^2+5.86^{**}Z-0.35^{NS}Z^2+0.26^{NS}XZ$	84.14
	DFM	$Y=21.92^{**}+2.13^{NS}X-0.37^{NS}X^2+0.21^{NS}Z-0.02^{NS}Z^2+0.02^{NS}XZ$	76.65
MC	NFH	$Y=10.75^{**}+0.77^{NS}X-0.16^{NS}X^2-1.05^{**}Z+0.03^{NS}Z^2+0.03^{NS}XZ$	67.83
	PT	$Y=5.31^{**}-0.22^{NS}X-0.01^{NS}X^2-0.11^{**}Z+0.001^{NS}Z^2+0.02^{NS}XZ$	59.27
	FFM	$Y=440.31^{**}-5.36^{NS}X-1.15^{NS}X^2+5.54^{**}Z-0.24^{NS}Z^2-0.45^{NS}XZ$	73.75
	DFM	$Y=37.86^{**}+1.08^{NS}X-0.32^{NS}X^2+0.39^{NS}Z-0.02^{NS}Z^2-0.02^{NS}XZ$	76.06
MB/MC	NFH	$Y=509441.66^{**}+489725.68^{**}X-52085.12^{**}X^2+9599.39^{NS}Z-460.40^{NS}Z^2+8761.59^{**}XZ$	95.88
	FY	$Y=7153.50^{NS}+12945.88^{NS}X-1217.05^{NS}X^2+104.74^{**}Z+10.19^{NS}Z^2+33.19^{NS}XZ$	85.18

Note: C = Complete; R = Reduced; IM = Model identity; MB = Mocambinho; MC= Montes Claros; Var. = Variables; Munc.= Municipalities; SV = Source of variation; m = Model; r = residue; F = F-test; p = p-value; NFP = Number of fruits per plant; PT = Pericarp thickness; FFM = Fresh fruit mass; DFM = Dry fruit mass; NFH = Number of fruits per hectare, FY = Fruit yield.

In Montes Claros, up to six fruits per plant were estimated at a density of 33,000 holes per hectare, with three plants per hole (Figure 1A). In Mocambinho, up to four and a half fruits per plant were estimated at a density of 39,000 holes per hectare, with three plants per hole (Figure 1B).

Extrapolating the number of fruits per plant to fruits per hectare revealed that under the conditions of this study, with up to six fruits per plant produced at a density of 33,000 holes per hectare with three plants per hole, the number of fruits per hectare reached 594,000-significantly higher than the 259,974 fruits produced with a population of 3,333 plants per hectare.

In Montes Claros, the highest planting density of 66,000 holes per hectare with 20 plants per hole resulted in a greater pericarp thickness of 4.80 mm (Figure 1C). A similar high pericarp thickness of 4.50 mm was observed at a density of 13,000 holes per hectare with three plants per hole. In Mocambinho, a pericarp thickness of approximately 3.50 mm was estimated at densities of 41,000 and 44,000 holes per hectare with three and 20 plants per hole, respectively (Figure 1D).

Fresh (Figure 2A and B) and dry (Figure 2C and D) fruit masses were higher in Montes Claros than in Mocambinho. The highest fresh fruit mass of 46.00 g was observed at a density of 13,330 holes per hectare with three plants per hole in Montes Claros (Figure 2A). In Mocambinho, the estimated fresh mass was 34.00 g at a density of 30,000 holes per hectare with three plants per hole (Figure 2B).

The estimated dry mass in Montes Claros was 4.10 g at a density of 13,000 holes per hectare with three plants per hole (Figure 2C). In Mocambinho, the estimated dry mass was 2.60 g at a density of 36,000 holes per hectare with three plants per hole.

The highest estimated number of fruits per hectare was approximately 1,620,000 units, obtained at a density of 64,000 holes per hectare with 20 plants per hole, with no significant difference between the sites studied (Figure 3A). Notably, although this density resulted in the highest number of fruits per hectare, the number of fruits per hole and plant was the lowest.

According to the model identity test, there was no difference in fruit yield between the cities of Montes Claros and Mocambinho (Table 2). The highest yield was 56,489.63 kg ha^{-1}, which was obtained at a density of approximately 60,000 holes per ha and 20 plants per hole.

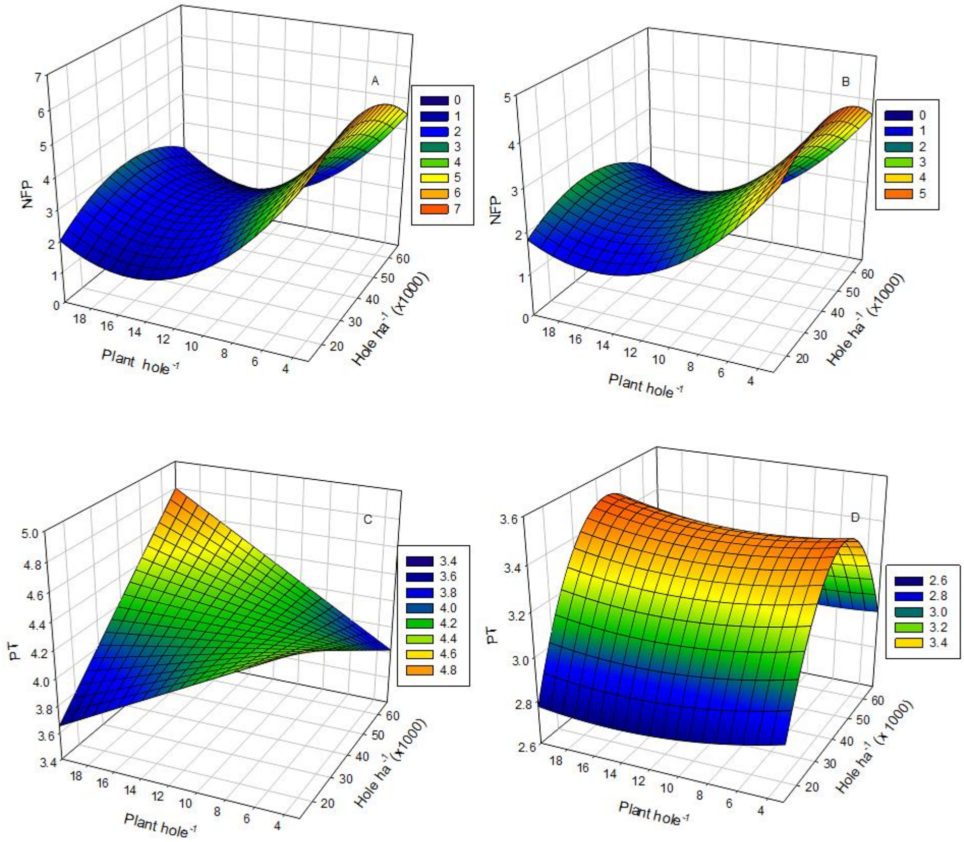

Figure 1. Response surface for the number of fruits per plant (NFP) and pericarp thickness (PT) of *Cucumis anguria* L. as a function of the number of holes per hectare (13.33, 20.00, 50.00, and 66.66 thousand) and number of plants per hole (3, 5, 10, and 20) in Montes Claros - MC (A and C) and Mocambinho - MB (B and D), Minas Gerais State, Brazil.

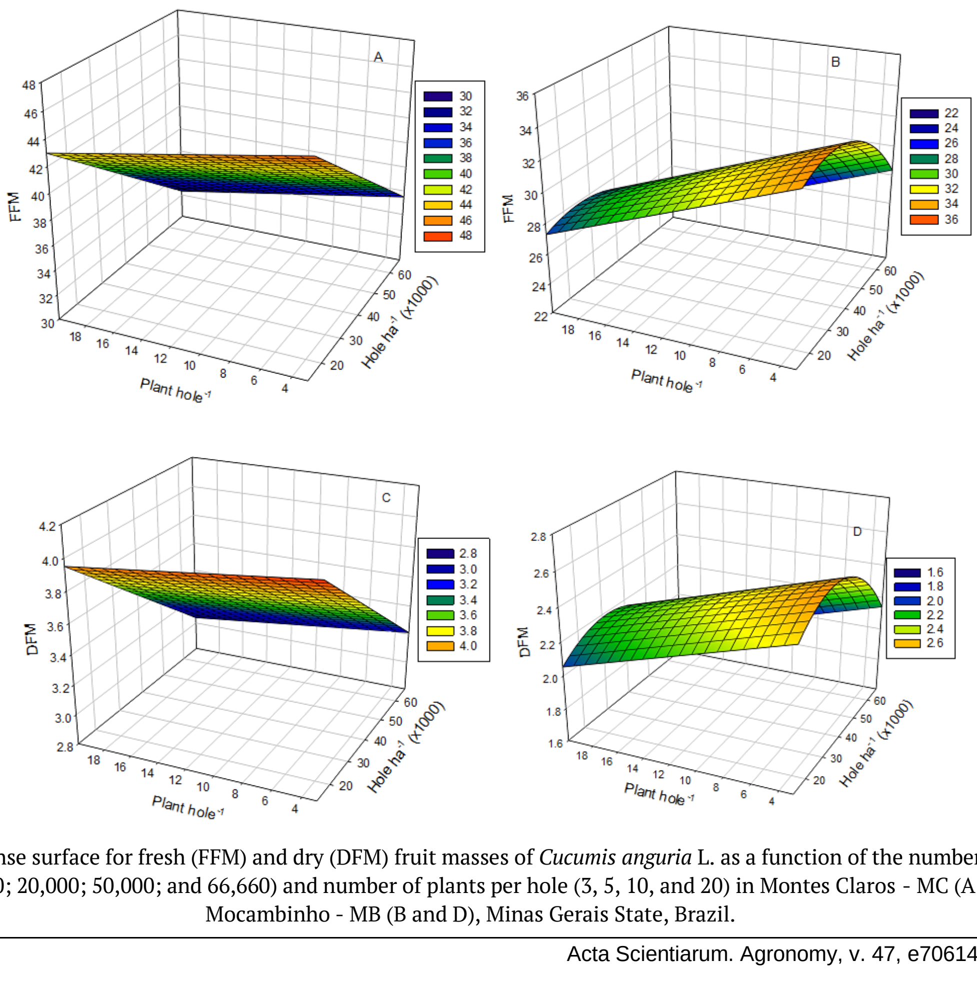

Figure 2. Response surface for fresh (FFM) and dry (DFM) fruit masses of *Cucumis anguria* L. as a function of the number of holes per hectare (13,000; 20,000; 50,000; and 66,660) and number of plants per hole (3, 5, 10, and 20) in Montes Claros - MC (A and C) and Mocambinho - MB (B and D), Minas Gerais State, Brazil.

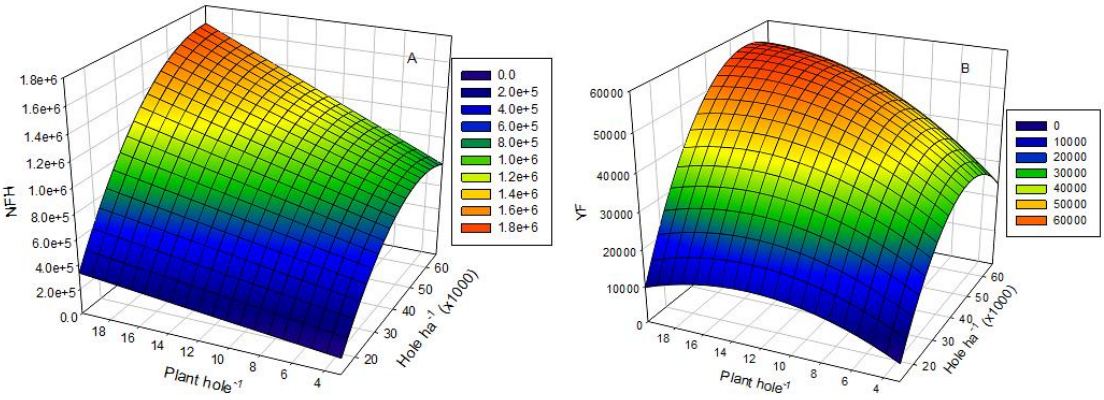

Figure 3. Response surface for the number of fruits per ha (NFH) and fruit yield (FY) of *Cucumis anguria* L. as a function of the number of holes per hectare (13,330; 20,000; 50,000; and 66,660) and number of plants per hole (3, 5, 10, and 20) in Montes Claros (MC) and Mocambinho (MB), Minas Gerais State, Brazil.

Discussion

Our findings on determination coefficients indicate good predictability for the estimates of the evaluated variables (Piepho, 2019). High NFP values were observed at higher planting densities, considering the total number of holes per hectare evaluated. However, at densities exceeding three plants per hole, there was a reduction in the number of fruits per plant. Oliveira et al. (2010) reported up to 78 fruits per plant at a spacing of 3 x 1 m, equivalent to 3,333 plants or holes per hectare, with one plant per hole. In contrast, the densification of plants per hole in the present experiment led to lower fruit production per plant compared to conventional spacing. This reduction is likely due to increased intraspecific competition for resources such as water, light, nutrients, and space (Sun et al., 2021).

A higher number of fruits and greater pericarp thickness were observed in Montes Claros compared to Mocambinho, likely due to the environmental conditions of the region. For fresh consumption, thicker pericarp fruits are ideal, suggesting greater potential for the production of fresh maxixe in the Montes Claros region. However, both locations have the potential to produce quality fruits for canning.

In both locations, increased plant density per hectare resulted in reduced fresh and dry masses. This relationship has been documented in other studies as well. For the Northeast maxixe cultivar, the highest fresh mass was achieved with a spacing of 3 x 1 m and one plant per hole, corresponding to a density of approximately 3,333 holes per hectare (Oliveira et al., 2010). Similar trends were observed in squash cultivars (Resende et al., 2013) and mini watermelon hybrids (Gomes et al., 2017).

Increasing plant density leads to a decrease in fruit mass, primarily due to shading from lower leaves, which reduces sunlight absorption and subsequently decreases the photosynthetic rate, resulting in lower fruit mass (Gomes et al., 2017). To ensure maximum efficiency in plant production, it is crucial to establish an optimal number of plants that achieve the ideal leaf area for maximum sunlight absorption, which is essential for photosynthesis. Therefore, plant population density is critical in balancing sunlight absorption with the growth of vegetative parts and fruit production (Oliveira et al., 2010).

Variations in dry and fresh fruit masses, fruit numbers per plant, and pericarp thickness between locations are common. These variables are polygenic and strongly influenced by the environment, leading to different performances of the same cultivar in various locations (Anderson et al., 2014).

An increase in plant density resulted in higher fruit numbers per hectare and, consequently, increased productivity. Similar findings have been reported in the Northeastern maxixe cultivar (Oliveira et al., 2010), in squash (Resende et al., 2013), and in mini watermelon hybrids (Gomes et al., 2017).

The agronomic performance of maxixe varies with spacing, plant density per hole, and the environmental conditions of the cultivation site. Decreasing spacing and increasing the number of plants per hole result in a higher plant population per hectare, which translates to more fruits per hectare and higher productivity. However, this increase does not necessarily improve the qualitative aspects of the fruit. In general, Cucurbitaceae planted at high densities produce large numbers of fruits, but often of uneven sizes, many of which do not meet commercial standards.

Conclusion

Planting maxixe at higher densities leads to the highest yields in weight and number of fruits per area. However, the number of fruits per plant, as well as the fresh and dry masses of the fruits, decreases under high-density conditions. Therefore, considering both production per area and plant, intermediate planting densities are most suitable for maxixe cultivation, as they optimize yield without compromising fruit quality. For the highest number of fruits per hectare, the recommended density is 33,000 holes per hectare with three plants per hole. Similar yields can also be achieved with spacings of 1.00 x 0.30 or 0.85 x 0.35 m.

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