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Production and quality of gherkin seeds under high-density planting

Producción y calidad de semillas maxixe en alta densidad de siembra

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ABSTRACT

Research on gherkin seed production technology is scarce, resulting in the use of production techniques that might not express the full crop potential to produce seeds in terms of quantity and quality. In this scenario, high-density planting could be a good option to increase gherkin yield in seed production. This study aimed to evaluate the production and quality of gherkin seeds under high planting densities. The treatments consisted of two planting sites in northern Minas Gerais, Brazil. The high-density planting system favored the increase in production without affecting the quality of gherkin seeds up to a certain limit. Although the maximum seed yield was achieved at the density of 50,000 holes per hectare and 20 plants per hole (population of 1,000,000 plants per ha), seed quality is maintained up to densities of 39,000 holes per ha and 20 plants per hole (780,000 plants per ha) with regard to germination, and at densities of up to 44 thousand holes per ha and 11 plants per hole (484,000 plants per ha) with regard to the germination speed index.

Keywords: *Cucumis anguria* L., vegetable, high density planting, germination, vigor.

RESUMEN

La investigación sobre tecnología para la producción de semillas de Maxixe, una hortaliza tradicional cultivada en Brasil, es escasa. Esto conduce al uso de técnicas en campos de producción que pueden no expresar todo el potencial del cultivo en términos de rendimiento y calidad de semilla, como la densificación de plantación. El objetivo del trabajo fue evaluar la producción y calidad de semillas de Cucumis anguria bajo altas densidades de siembra. Los tratamientos consistieron en dos sitios de plantación en el norte de Minas Gerais, donde hay campos de producción de semillas. El sistema de superdensificación de plantas favorece el aumento de la producción, sin afectar la calidad de las semillas del cultivo producidas hasta cierto límite. Aunque la máxima productividad de semillas se alcanza con una densidad de 50.000 huecos por hectárea y 20 plantas por hueco (población de 1.000.000 de plantas por ha), la calidad de la semilla se mantiene hasta densidades de 39.000 huecos por hectárea y 20 plantas por hueco (780.000 plantas por ha), cuando se observa la germinación. Al considerar el índice de velocidad de germinación, la calidad de la semilla se mantiene hasta densidades de 44.000 hoyos por ha y 11 plantas por hoyo (484.000 plantas por ha).

Palabras Claves*: Cucumis anguria L., hortaliza, alta densidad de plantación, germinación, vigor.*

Introduction

Gherkin (*Cucumis anguria* L.) is a underutilized vegetable of the family Cucurbitaceae, showing high adaptability to regions with temperatures above 20 ºC (Kinupp; Lorenzi, 2014, Reis *et al*., 2013). The species was introduced to Brazil by enslaved Africans and has since adapted well to the North and Northeast regions of the country. According to the Agricultural Census of 2017, the North and Northeast regions produced 9,964 and 9,484 tons of gherkin, respectively, amounting to more than 71% of the national production (IBGE, 2019).

The growing market demand for this crop has increased the search for high-quality seeds. However, since this vegetable is usually produced under low technological investment, there is still no significant interest in developing new gherkin cultivars, currently limited to a few commercial varieties in Brazil. Furthermore, information is still required in order to optimize seed production and quality in crops such as gherkin.

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Studies on production technologies for gherkin seed are scarce, leading to the application of field production techniques that might not express the full potential of this crop in terms of seed yield.

Some gherkin producers have used high-density planting to improve the seed yield per area. This technique, whose purpose is to obtain maximum production per area, has been used in crops such as rice (Saju; Thavaprakaash, 2020), mango (Dalvi *et al.*, 2010), citrus (Ladanya *et al.*, 2019), asparagus (Brock, 2012; Li *et al.*, 2014), tomato (Maboko; Plooy, 2013), and onion (Ojha *et al.*, 2021).

However, studies on high-density planting aiming to produce vegetable seeds in Brazil are yet non-existent. Furthermore, there are no reports in the literature about the density recommendations for gherkin plants in seed production fields and their influence on seed production and quality, especially under high-density planting conditions.

Therefore, the present study aimed to evaluate the production and physical and physiological quality of gherkin seeds as a function of different planting densities.

Material And Methods

The experiment was conducted in the municipality of Montes Claros-MG at the Experimental Area of the Institute of Agricultural Sciences of the Federal University of Minas Gerais - UFMG (latitude: 16º40'56''S, longitude: 43º50'23''W, at an elevation of 646 m a.s.l.), and in Mocambinho, a district of Jaíba-MG, one of the main producing regions of vegetable seeds in the state (latitude: 15º07'00''S longitude: 44º00'28''W at an elevation of 681 m a.s.l.).

The treatments consisted of two planting locations (Mocambinho "MOB" and Montes Claros "MOC"), four numbers of plants per hole (3, 5, 10, and 20), and four numbers of holes per hectare (13.33, 20, 50, and 66.66 thousand holes ha^{-1}) referring to the spacings of 1.50x0.50, 1.00x0.50, 0.80x0.25, and 0.60x0.25 m, respectively), with four replicates. The experiment was set up in a 4x4 arrangement following a randomized block design.

The correct number of plants per hole was obtained by directly sowing from five to 25 seeds per hole. The plants were then thinned to the correct number of plants per hole ten days after sowing. Each plot consisted of 12 holes, with the number of plants varying according to the treatment. The usable area consisted of two central holes.

Fertilization was performed according to the expected spacing and number of plants, using as a reference the P_2O_5 content required per m² according to the recommendations of Embrapa Hortaliças. Low-fertility soils were fertilized using 400 kg ha^{-1} of 4-30-10 NPK.

Fruit harvest was performed 80 days after sowing in both locations. Seed extraction was performed manually at the laboratory using a sample of ten fruits for each treatment, during which the seeds and impurities were deposited in containers to ferment for 24 hours. After fermentation, the material was washed in running water to remove all the mucilage and then shade-dried for 72 hours.

The following parameters were evaluated according to Brasil (2009): 100-seed mass, seed dry matter, seed weight per area, germination, first germination count, germination speed index, and seedling dry matter.

The joint analysis was performed using the following model: $y_{ijkl} = m + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} + R_l/C_k + e_{ijkl}$, where A is the number of plants per hole) and B is the number of holes per ha, serving as quantitative factors. C corresponds to the location, serving as a qualitative factor. Subsequently, the multiple regression adjustment was performed for the two locations (complete model) and at the mean level (reduced model). Therefore, a regression model was adjusted for each environment when the behavior was statistically different between environments. A single adjusted regression model was considered when the behavior was similar in both environments.

The response surface plots were constructed based on the values predicted by the regression models. The significance of the regression coefficients was determined by the t-test ($p \leq 0.05$). All statistical analyses were performed with the software R, whereas the representations in response surfaces were provided by the software SigmaPlot.

Results and discussion

The analysis of variance revealed significant statistical differences in the 100-seed mass of gherkin, with a significant interaction between the number of holes per ha (CPHA) and the number of plants per hole (PPC), and also between the location and the CPHA (Table 1).

Considering the relationship between the CPHA and PPC on the 100-seed mass and the models

Table 1. Summary of the joint analysis of variance for the physical and physiological characteristics of gherkin seeds as a function of planting density (holes per ha – CPHA and plants per hole - PPC) and two planting locations (LOC).

Variables	M100	PSPL	PSH	GERM	PCONT	GSI	MSP
LOC/Block	5.25010^{-4ns}	0.0004617^{s}	260584^{ns}	199.5^{ns}	170.46^{ns}	1.11^{ns}	$5.96\ 10^{-3ns}$
LOC	0.02**	0.0006217^{ns}	2740781**	4324.5**	18336.13**	0.15^{ns}	0.18**
CPHA	0.02**	0.0038448**	11285400**	2539.5**	1081.46**	10.65**	0.03**
PPC	$5.93\ 10^{-3}$**	0.0155330**	4010857**	556.8**	155.79^{ns}	5.60**	0.01**
CPHA x PPC	$2.58\ 10^{-3}$**	0.0003710^{ns}	1103803**	188.7^{ns}	830.01**	2.11**	0.01**
LOC x CPHA	$3.71\ 10^{-3}$**	0.0003542^{ns}	188383^{ns}	250.8^{ns}	436.79**	3.63**	0.01**
LOC x PPC	$5.20\ 10^{-5ns}$	0.0001191^{ns}	8842348**	48.8^{ns}	109.13^{ns}	3.13**	$5.92\ 10^{-3ns}$
LOCxCPHAxPPC	$1.23\ 10^{-3ns}$	0.0003491^{ns}	2242668**	154.7^{ns}	94.24^{ns}	4.33**	$6.88\ 10^{-3}$**
CV (%)	5.67	39.03	49.89	19.10	33.79	16.95	46.96

^{ns} Not significant; ** significant at 1% by the F-test. M100 (100-seed mass), PSPL (seed weight per plant), PSH (seed weight per ha), GERM (germination), PCONT (first count), GSI (germination speed index), and MSP (seedling dry matter).

adjusted for the data obtained, the CPHA interfered more with this variable than the PPC, showing a quadratic effect (Figures 1A and 1B). Low CPHA intensities caused minor changes in the 100-seed mass at the different PPC levels, justifying the CPHA x PPC interaction observed.

The maximum 100-seed weight was 0.62 g, achieved with 47 thousand holes per hectare and 12 plants per hole in Mocambinho (MOB) (Figure 1A). In Montes Claros (MOC), the maximum weight was 0.67 g (Figure 1B), achieved with 41 thousand holes per ha and 12 plants per hole (Figure 2B). Therefore, based on these results and considering the densities used in the present study (CPHA: 13.33 thousand to 66.67 thousand; PPC: 3 to 20), the 100-seed mass was obtained at intermediate densities in both locations.

The 100-seed mass indicates the weight and size of seeds, i.e., seed quality. Seed size and weight are among the most affected parameters during field production, and it should be noted that seed quality is obtained in the field.

Seed weight is directly related to seed vigor: therefore, the heavier the seeds, the higher their weight. It can also be said that, up to a certain limit, the increase in planting density provided more vigorous seeds, allowing a better embryo formation and a more efficient initial growth.

Seed production per plant was significantly affected by the isolated CPHA and PPC factors (Table 1). The response of both factors was quadratic in MOB, reaching 80.76 g of seeds per plant with 30 thousand holes per ha and three plants per hole (Figure 2A). On the other hand, the PPC showed a quadratic response in MOC, whereas the CPHA showed a decreasing linear response. The maximum estimated value was 90.14 g of seeds per plant with 39 thousand holes per ha and three plants per hole (Figure 2B). In the shaded area of the plots, maximum production per plant occurred under the lowest PPC density and at an intermediate CPHA density, which could be justified by the lower plant competition for photoassimilates, resulting in a higher seed production per plant. On the other hand, under the maximum density used in the present study, the production decreased by 83.16% and 96.89% in MOB and MOC, respectively.

Seed production per area was significantly affected by the CPHA x PPC interaction, the interaction between the location and PPC, and the interaction between the three factors (Table 1). Both CPHA and PPC showed a quadratic response in MOB, reaching the maximum value of 2,209.53 kg of seeds per ha with 10 PPC and 66.66 thousand CPHA (Figure 3A). In MOC, the effect of the CPHA x PPC interaction resulted in different behaviors of one factor at each level of the other factor, with the lowest planting density showing no significant difference when the number of holes per ha was increased.

However, there was a significant quadratic effect as the density of holes per area increased. The maximum estimated production was 3.599,35 kg of seeds per ha, with 50 thousand CPHA and 20 PPC (Figure 3B). The higher numbers of plants were undoubtedly responsible for the higher gherkin seed yield since high densities decreased seed production per plant.

The total seed weight is directly related to the number of fruits per hectare, with the number of

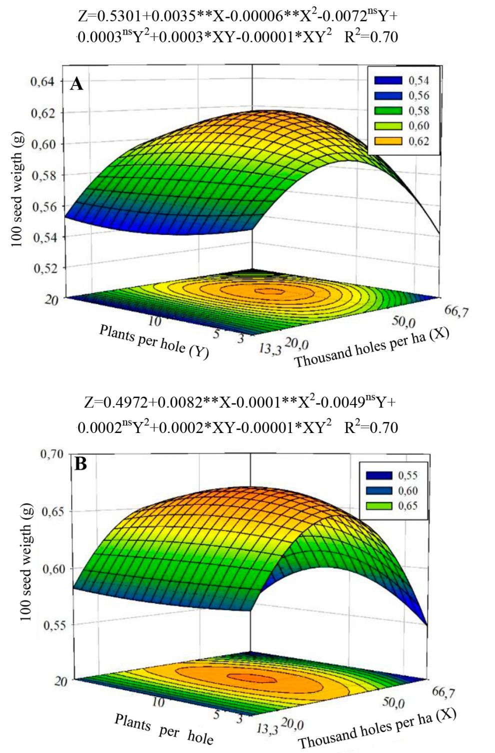

Figure 1. Gherkin (*Cucumis anguria L.*) 100-seed mass in Mocambinho (A) and Montes Claros (B) as a function of different planting densities. * and ** Significant at 5% and 1% by the t-test, respectively.

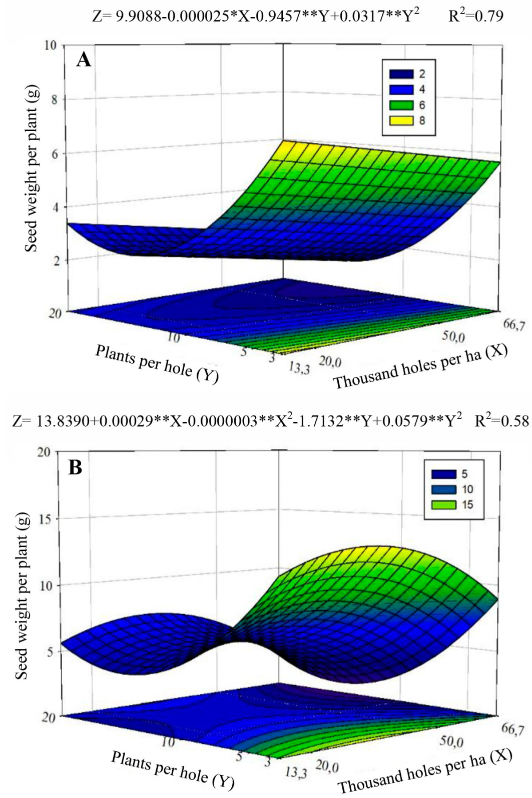

Figure 2. Gherkin (*Cucumis anguria L.*) seed weight per plant in Mocambinho (A) and Montes Claros (B) as a function of different planting densities. * and ** Significant at 5% and 1% by the t-test, respectively.

fruits increasing with the increase in planting density, consequently increasing the total seed weight per area.

Planting density becomes unfeasible above 50 thousand holes per hectare, resulting in withered and malformed seeds without complete embryo formation. Therefore, these seeds are not capable of forming new plants.

The treatment with the best response on seed weight per hectare corresponded to the maximum density in gherkin planting for seed production.

There is still no consolidated information about gherkin yield (Kg/ha). Nascimento *et al.* (1994) observed that the total seed weight produced by gherkin plants in 1989 was 1,901 kg.

Vegetable seed production companies have field production estimates reaching up to 1,500 kg of seeds per hectare by producers already experienced in the activity, with a mean value of 900 kg per hectare of seeds with good physiological quality and a mean germination rate of 89%. However, there are still no scientific publications based on previous results obtained by registered producers.

Therefore, in order to obtain high-quality seeds, planting should be performed with 50 thousand holes per hectare and ten plants per hole, totaling 500,000 plants per hectare and reaching the maximum physiological potential. For larger volumes, the ideal plant population is 1,000,000 plants (50 thousand holes and 20 plants per hole).

Seed germination was only influenced by the isolated factors (Table 1). However, when the equation was adjusted as a function of the CPHA and PPC for each location, the only significant effect was observed on PPC. In MOC, the increase in planting density per ha resulted in a quadratic increase in the germination of gherkin seeds, with the maximum estimated value of 83.70% when using 39 thousand holes per ha (Figure 4A). Starting at the lowest density of holes per ha, the increase in this variable increased seed germination up to the maximum value mentioned, after which there was

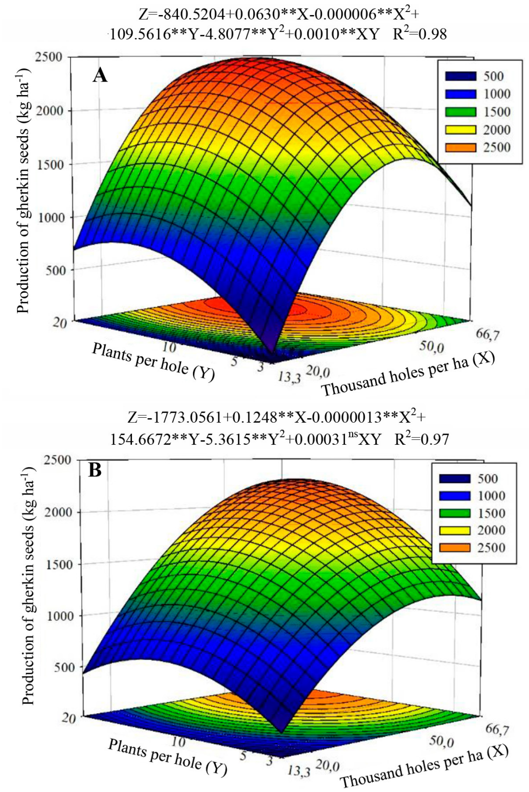

Figure 3. Production of gherkin seeds (*Cucumis anguria L.*) per area in Mocambinho (A) and Montes Claros (B) as a function of different planting densities. * and** Significant at 5% and 1% by the t-test, respectively.

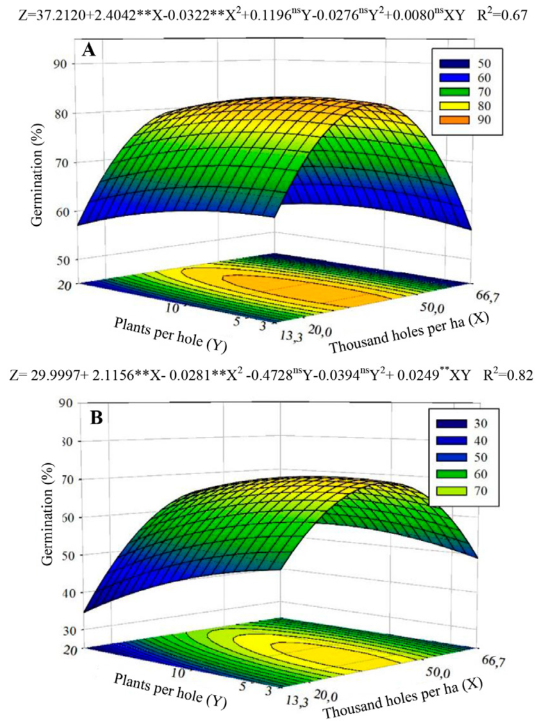

Figure 4. Germination of gherkin seeds (*Cucumis anguria L.*) per plant in Mocambinho (A) and Montes Claros (B) as a function of different planting densities.

a decrease until the maximum density used in this study (66.67). The germination rate at the highest density employed was 33% lower than the maximum value mentioned.

There was also a quadratic response of germination with the increase in the number of holes per ha in MOC. The maximum germination rate was 71.30% when using 41 thousand holes per ha (Figure 4B). Similar to MOB, the increase in the number of holes per ha reduced germination by 51.5% after the maximum germination value.

There are reports in the scientific literature about the germination of gherkin seeds under laboratory conditions, with germination rates ranging from 54 to 90% (Souza Neta *et al.*, 2016), 2 to 70% (DA Silva *et al.*, 2019), and 97.5 to 98.5% (Alves *et al.*, 2014).

The seed development process comprises the point of physiological maturity, which is the intersection between the maximum germination, vigor, and dry matter accumulation, when the seeds achieve the best productive potential and there are no more gains in dry matter. Medeiros *et al.* (2010) stated that gherkin physiological maturity occurs about 40 days after anthesis. Da Silva *et al.* (2019), in turn, stated that the same point occurs 56 days after flower opening.

The first germination count was significantly affected by the CPHA x PPC and Location x CPHA interactions (Table 1). The coefficients of the CPHA x PPC interaction were significant in the adjusted equation in both MOB and MOC. In Mocambinho, the CPHA alone did not influence the first count but contributed to different PPC results at each CPHA level (Figure 5A). The maximum value achieved by germination was 57.35% when using 47 thousand holes per hectare and 20 plants per hole (Figure 5A). In Montes Claros, both CPHA and PPC showed a quadratic, slightly increasing response followed by a marked decrease under high densities (Figure 5B). The maximum estimated value was 29.19% when using 39 thousand plants per ha and 11 plants per hole (Figure 5B).

These results demonstrated that the conditions of Mocambinho were more favorable for providing normal seedlings than those of Montes Claros.

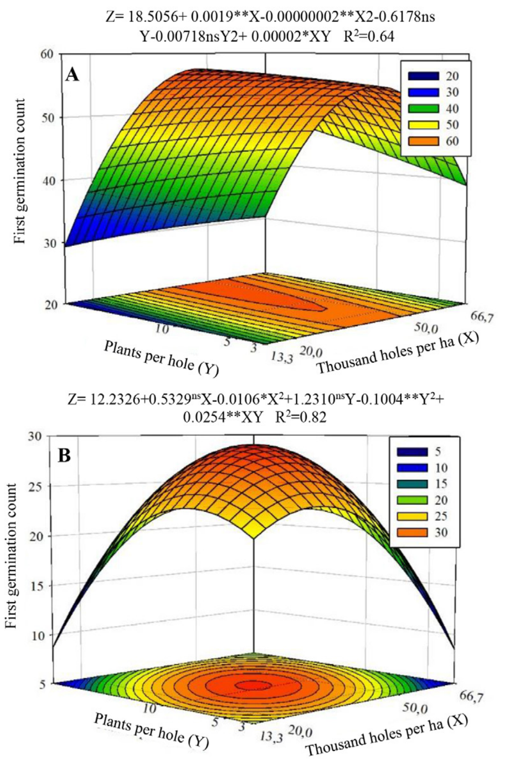

Figure 5. First germination count of gherkin seeds (*Cucumis anguria* L.) per plant in Mocambinho (A) and Montes Claros (B) as a function of different planting densities.

Moreover, high planting densities are harmful to the physiological quality and the number of regular seedlings. These findings could be associated with the type of soil found in Mocambinho since gherkin plants prefer sandy soils.

Schimidt *et al.* (2017) evaluated the dormancy breaking of gherkin seeds and observed first germination counts ranging from 2 to 93%. In another study, Paiva *et al.* (2017) obtained values ranging from 23 to 90% for the first germination count using the same gherkin variety as in the present study.

Plant accumulation in the same hole has shown to be harmful to producing seeds with sufficient reserves to result in high-quality seedlings during initial plant development. Therefore, treatments with ten plants per hole were the most effective in capturing resources for fruits, consequently resulting in better-formed seeds.

Cardoso (2003) shows that seed lots with higher vigor, especially with higher germination speed indices, are essential to obtain seedlings that will withstand adverse conditions such as lodging for less time and also obtain early and more uniform seedlings.

The first germination count is related to the physiological quality of seeds and is used to evaluate vigor through the count of normal seedlings. For gherkin, this count is performed on the fourth day, whereas the final germination count is performed on the eighth day (BRASIL, 2009).

Seedlings are connected to the seed reserve tissues and contain all essential structures with the potential to generate a new plant under favorable environmental conditions. Abnormal seedlings exhibit some type of apparent abnormality and might not contain all essential structures, or these could be still under formation or malformed, with no potential to form a new plant. Therefore, the satisfactory establishment of these structures is essential for the plant to start absorbing nutrients and initiate the photosynthesis process.

The higher seed weight and fresh and dry matter accumulation shown before had reflections on physiological seed quality, resulting in higher germination rates, GSI, and first germination count values. Therefore, there was more seed vigor in the treatment with 50 thousand holes and ten plants per hole, thus resulting in more physiological quality.

The interactions significantly affected the GSI of gherkin seeds (Table 1). In MOB, there was a quadratic effect of CPHA at each PPC level. However, PPC had no significant relationship with GSI. The maximum point (7.37) was achieved when the number of holes per hectare was 44 thousand and the number of plants per hole was 11 (Figure 6A). In MOC, both CPHA and PPC had a quadratic effect on the GSI. The maximum estimated value was 7.22 when using 41 thousand CPHA and 13 PPC (Figure 6B).

Plant excess in the same hole, especially at the highest densities, negatively affected gherkin seed quality, demonstrating that the production of gherkin seeds with high vigor is damaged by plant excess.

Under high planting density conditions, competition can interfere with appropriate plant development. Although there are no records of the effects of high planting density on gherkin or even other Cucurbitaceae, this parameter has been studied in other plant families. LI *et al.* (2019) observed that the maize grain yield was reduced under high planting density conditions due to the high competition for nutrients, especially at the flowering stage.

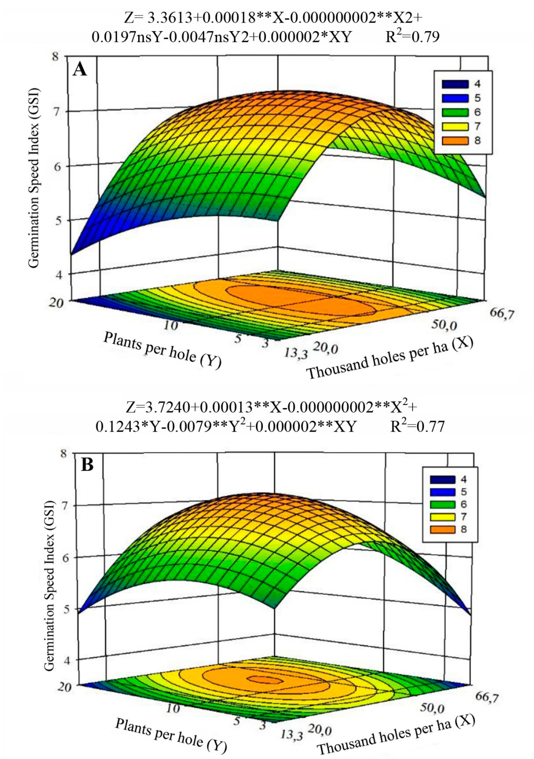

Figure 6. Germination Speed Index (GSI) of gherkin seeds (*Cucumis anguria L.*) per plant in Mocambinho (A) and Montes Claros (B) as a function of different planting densities.

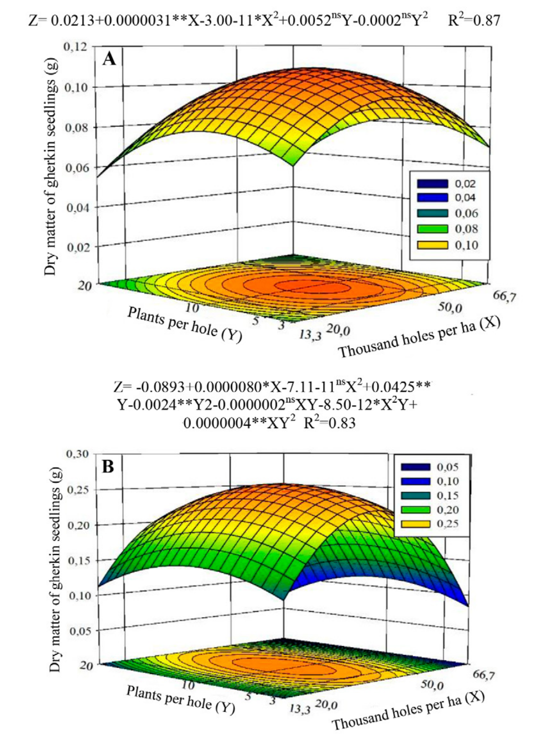

Figure 7. Dry matter of gherkin seedlings (*Cucumis anguria L.*) per plant in Mocambinho (A) and Montes Claros (B) as a function of different planting densities.

The GSI values obtained in the present study ranged from 4.5 to 7.11. The values found by other authors in laboratory tests using water and blotting paper ranged from 3.02 to 13.4 (Almeida *et al.*, 2019) and from 4.0 to 1.00 (ARAÚJO *et al.*, 2011).

The loss in germination speed is mainly related to damage to the energy mechanisms that produce a cascade effect and decrease the germination uniformity, resistance to stresses, and field emergence. Moreover, vigor can also be evaluated through the mean germination speed and germination synchronicity.

The interactions significantly affected the dry seedling matter (Table 1). There was a quadratic effect of CPHA at each PPC level in MOB. However, this effect had no significant influence on seed dry matter. The maximum estimated value was 0.11g when using 41 thousand holes per ha and ten plants per hole (Figure 7A). In MOC, the maximum weight was 0.27g when using 39 thousand holes per ha and 12 plants per hole (Figure 7B). Seedling dry matter production is related to the seed reserve stocks, responsible for developing primary tissues.

Donato *et al.* (2015) obtained similar results to this statement in an experiment conducted with melon, reporting that seedling dry matter production is intimately related to the seed reserve stocks.

Since seeds with more reserves produce more vigorous plants with higher dry and fresh matter accumulation, the treatments with up to ten plants per hole produced seeds with superior physiological quality, resulting in the establishment of large seedlings with uniform growth, a high percentage of emergence, and a high storage potential. Nascimento (2011) stated that vigorous seeds usually result in vigorous seedlings, i.e., with greater competition capacity and higher survival rates. The loss of vigor, verified by the decrease in the number of regular seedlings, is related to membrane integrity damage.

Up to a certain limit, the high-density planting system favors the increase in production without affecting the quality of gherkin seeds. Although the maximum seed yield was achieved at the density of 50 thousand holes per hectare and 20 plants per hole (population of 1,000,000 plants per ha), seed quality is maintained at densities of up to 39 thousand holes per ha and 20 plants per hole (780,000 plants per ha) with regard to germination, and at densities of up to 44 thousand holes per ha and 11 plants per hole (484,000 plants per ha) with regard to the GSI.

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