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CLOVE-SEED SIZE AND HEALTH AND PLANT SPACING ON THE VIABILITY OF GARLIC CROPS[1]

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ABSTRACT – Garlic is a vegetable that has a high economic importance for Brazil. However, despite increases in garlic bulb production in the last years, Brazil is still dependent on imported garlic to meet the national demand. Thus, proper management practices and the use of virus-free clove-seeds are promising alternatives to ensure a high productivity and profitability. Thus, the objective of this work was to evaluate production characteristics and profitability of conventional and virus-free garlic crops as a function of different clove-seed sizes and plant spacings. Two experiments were conducted simultaneously, using virus-free and conventional garlic plants in Portalegre, state of Rio Grande do Norte, Brazil, in a randomized block experimental design, with four replications. The treatments were arranged in split-plot, with the clove-seed size (large and small) in the plots, and the spacing between plants (7.5, 10.0, 12.5, and 15.0 cm) in the subplots. The combination between the use of virus-free clove-seeds, large clove-seed size, and spacing of 12.5 cm between plants resulted in the highest commercial bulb yield and net income, R$ (BRL) 85,151.00 ha^{-1}. The use of large clove-seeds and spacing of 7.5 cm between plants are recommended for conventional garlic crops.

Keywords: *Allium sativum* L. Profitability. Density of planting.

VIABILIDADE DO CULTIVO DE ALHO EM FUNÇÃO DA SANIDADE, TAMANHO DO BULBILHO E ESPAÇAMENTO

RESUMO – O alho é uma hortaliça de grande importância econômica para o Brasil. No entanto, apesar da produtividade do alho brasileiro ter aumentado nos últimos anos, ainda há uma dependência do alho importado para atender a demanda interna. Dessa forma, práticas de manejo e o uso de alho-semente livre de vírus, tornam-se uma alternativa promissora para garantir maiores produtividades e rentabilidade. Assim, o objetivo deste trabalho foi avaliar características de produção e rentabilidade do cultivo de alho convencional e livre de vírus em função do tamanho de bulbilho-semente e espaçamento entre plantas. Dois experimentos foram conduzidos simultaneamente, utilizando alho livre de vírus e convencional, em Portalegre-RN. O delineamento experimental foi o de blocos casualizados, com quatro repetições. Os tratamentos foram dispostos em parcelas subdivididas, sendo as parcelas representadas pelo tamanho dos bulbilhos: grande e pequenos. As subparcelas foram compostas por quatro espaçamentos entre plantas: 7,5; 10,0; 12,5 e 15,0 cm. A combinação entre o alho-semente livre de vírus, bulbilho de tamanho grande e espaçamento de 12,5 cm entre plantas resultou em maior produtividade comercial e receita líquida (R$ 85.151,00 ha^{-1}). Para o alho convencional, sugere-se a utilização de bulbilhos grandes com espaçamento de 7,5 cm entre plantas.

Palavras-chave: *Allium sativum* L. Rentabilidade. Densidade de plantio.

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INTRODUCTION

Garlic (*Allium sativum* L.) is a vegetable that has high economic importance in Brazil. The current mean national garlic bulb yield is 11.61 Mg ha^{-1}. However, despite improvements in the last years, the Brazilian garlic production is still insufficient to supply the domestic market demand, which are met by imports from other countries, mainly China, Argentina, and Spain (IBGE, 2017). However, the addition of new technologies, such as the use of improved cultivars, vernalization, and mainly the adoption of virus-free clove-seeds has significantly increased the bulb yield and quality of garlic plants in Brazil, and the crop expansion to other regions of the country (SOUZA et al., 2011).

The use of virus-free clove-seeds has become a technological advance for the development of the garlic production chain in Brazil. It made possible the exploration of the maximum productive potential of the plants due to the eradication of viruses that are found in conventional (infected) seeds, and the obtaining more vigorous and productive plants (LUÍS et al., 2020). According to Resende et al. (1999), the use of plants from virus-free garlic seeds can increase the garlic bulb yield in up to 100% when compared to the use of conventional seeds.

Virus-free garlic seeds are obtained by a clonal cleaning, through the growing of stem apexes focused on recovering the health of garlic clones infected by viruses. Apical meristem cells, basal discs, and root ends are grown in vitro to reproduce new virus-free plants (MENEZES JÚNIOR, 2011); therefore, their seeds have higher prices than conventional ones.

In addition, the use of proper spacing between plants and clove-seed size are also crop management strategies that contribute to increase garlic bulb yield and profitability, and make the garlic Brazilian market more competitive. Plant spacing is an important factor for garlic crops, which affects the growth and development of plants. Changes in plant spacing affect the interception of light by leaves and the root water and nutrient absorptions, which affect the garlic bulb yield and size (MORAVČEVIĆ et al., 2011).

The use of short spacings between plants provides, in general, higher bulb production per area, but smaller bulb sizes (VIDYA, 2015). Contrastingly, large spacings result in larger bulbs and better commercial classification, due to the higher soil area for each plant and lowest competition (MUNEER et al., 2017), which generates a higher final garlic bulb yield and profitability.

The clove-seed size used is also important for the final garlic bulb yield (LIMA et al., 2019); the use of large clove-seeds result in higher bulb yields due to the higher vegetative growth caused by the higher quantity of nutritional reserves in the seeds (MAHADEEN, 2011).

The clove-seed size or weight to be used is defined base on the density of plants. Therefore, establishing an optimal population and clove-seed size is essential to maximize the exploration of production factors and ensure high bulb yields and profitability. Thus, the objective of this work was to evaluate production characteristics and profitability of conventional and virus-free vernalized garlic crops as a function of different clove-seed sizes and plant spacings.

MATERIAL AND METHODS

The study consisted of two experiments, one with virus-free garlic crops and other with conventional garlic crops, using seeds obtained from the Brazilian Agricultural Research Corporation (EMBRAPA). The experiments were conducted simultaneously from May to September 2017, in an experimental area in Portalegre, state of Rio Grande do Norte, Brazil (6°1'20"S, 38°1'45"W, and 520 m of altitude). The region has an Aw, tropical rainy climate, according to the Köppen classification, with a dry winter and a rainy season up to July. The climatic data in the area were monitored during the experiment and showed minimum temperatures between 15 and 21 °C, mean temperature of 24.7 °C, maximum temperatures between 26 and 34 °C, and a rainfall depth of 65 mm.

The soil of the experimental area was classified as a Lithic Udorthent, with weak A Horizon and medium texture (EMBRAPA, 2018). The soil chemical analysis showed pH (H_2O) of 4.60, 4.97 g Kg^{-1} of organic matter, 0.07 g kg^{-1} of N, 5.3 mg dm^{-3} of P, 79.7 mg dm^{-3} of K, 8.9 mg dm^{-3} of Na, 2.6 $cmol_c$ dm^{-3} of Ca, 1.3 $cmol_c$ dm^{-3} of Mg, 0.1 $cmol_c$ dm^{-3} of Al, and 2.31 $cmol_c$ dm^{-3} of H+Al.

A randomized block experimental design was used, with four replications. The treatments were arranged in split-plot, with the clove-seed size (large and small) in the plots, and the spacing between plants (7.5, 10.0, 12.5, and 15.0 cm) in the subplots; the spacing between planting rows was fixed in 20 cm, resulting in planting densities of 500.000, 375.000, 300.000 and 250.000 plants ha^{-1}, respectively. Large clove-seeds were those retained in the 1 and 2 sieves (15×25 and 10×20 mm meshes, respectively) and small clove-seeds were those retained in the 3 and 4 sieves (8×17 and 5×17 mm meshes, respectively).

The mean weight of the large and small sizes varied from 1.51 to 2.32 g and from 0.83 to 0.98 g, respectively, for the virus-free clove-seeds, and from 1.87 to 2.61 g and from 0.91 to 1.28 g, respectively, for the conventional clove-seeds.

The Roxo Pérola de Caçador garlic cultivar was used. The subplots consisted of beds of 0.2 m height, 1.0 m width, and 1.50, 2.00, 2.50, and 3.00 m length, respectively for the plant spacings of 20×7.5 cm, 20×10 cm, 20×12.5 cm, and 20×15 cm, with five planting rows, totaling 100 plants. The three central rows of each subplot were evaluated, discarding one plant from each end of the rows, resulting in a population of 54 plants.

The clove-seeds were subjected to a vernalization process for 50 days in a cold chamber at 4±2 °C and relative humidity of approximately 70%, before planting. The bulbs were withdrawn from the cold chamber at one day before planting for threshing. The cloves were then classified by size and planted according to the treatments adopted.

The soil was prepared using one plowing and one harrowing, and the beds were raised manually. The soil acidity was corrected by when the beds were raised by incorporating 400 kg ha^{-1} of $Ca(OH)_2$ to the soil. Soil fertilizers were applied at planting based on the soil chemical analysis, using 30 kg ha^{-1} of N (calcium nitrate), 180 kg ha^{-1} of P_2O_5 (simple superphosphate), 60 kg ha^{-1} of K_2O (potassium chloride), 15 kg ha^{-1} of Mg (magnesium sulfate), 12 kg ha^{-1} of Zn (zinc sulfate), 1.7 kg ha^{-1} of B (boric acid), and 75 Mg ha^{-1} of Pole Fértil® (a fertilizer based on bovine and chicken manure). Topdressing was applied at 20 and 50 days after planting (DAP), using 30 and 60 kg ha^{-1} of N (calcium nitrate and urea) respectively.

The plant health protection was done using mancozeb-based products for purple spot, and chlorfenapyr-based products for pests, such as thrips and mites. Weeds were controlled by manual weeding, when necessary.

A micro sprinkler irrigation system was used, with flow of 40 L h^{-1} and pressure of 200 KPa. The irrigation was suspended at three days before harvesting, when the plants were at the maturation stage, characterized by yellowing and partial drying of shoots. The plants were harvested manually at 104±4 DAP and subjected to a pre-cure process, consisted of keeping them exposed to the Sun for three days, and a shade cure, consisted of keeping them in a dry and airy place for 17 days. Then, the bulbs were subjected to cleaning.

Plant height (cm) from the ground level to the end of the longest leaf was evaluated at 60 DAP in ten plants of the area useful. Mean bulb weight (g), total bulb yield (Mg ha^{-1}), and commercial bulb yield (Mg ha^{-1}) were evaluated after the cure process. The commercial bulb yield is the yield of bulbs of commercial classes, those with transversal diameter above 32 mm and not sprouted, according to the Ordinance no. 242 of September 17, 1992 of the Brazilian Ministry of Agriculture, Livestock, and Supply (MAPA).

The economic analysis included calculations of production costs, as proposed by Martin et al. (1998). The nominal prices of all inputs were assessed from May to November 2017; the input prices and the machinery operational costs were obtained in the region of Portalegre and Mossoró, state of Rio Grande do Norte, Brazil. The labor cost was calculated based on the Breazilian minimum wage, R$ (BRL) 937.00 plus social charges equivalent to 10% of the minimum wage, resulting in a cost of R$ (BRL) 5.15 per working hour.

The profitability was determined for each treatment by calculating the total operational cost in R$ (BRL) ha^{-1} obtained by the sum of all production costs and the gross income in R$ (BRL) ha^{-1} resulted from the selling of the production, according to the bulb class. The garlic prices used were those practiced at the month of harvest by the Rio Grande do Norte State Food Supply Center, according to each class. The net income in R$ (BRL) ha^{-1} was obtained through the difference between the gross income and total operational cost.

The data were subjected to joint analyses of variance; the means of the variables affected by the clove-seed size and health were compared by the t test ($p \leq 0.05$), and those affected by the spacing between plants were compared by regressions analyses, by the F test ($p \leq 0.05$).

RESULTS AND DISCUSSION

The effect of the interaction between the spacing between plants, clove-seed health, and clove -seed size was significant for the mean bulb weight, total bulb yield, commercial bulb yield, and gross and net income. The effect of the interaction between the clove-seed size and of clove-seed health was significant for plant height; and the isolate effect of spacing was significant for plant height.

Virus-free garlic plants had higher heights than conventional ones, regardless of the clove-seed size planted, representing an increase of 13.5% and 20% for the use of small and large clove-seeds, respectively (Table 1).

Virus-free garlic plants had, in general, higher vegetative vigor than those from conventional (infected) seeds. This was found during all crop phenological stages, mainly in the period of higher vegetative growth, as found in other studies (RESENDE; FAQUIN; SOUZA, 2000; RESENDE; GUALBERTO; SOUZA, 2000). A gradual degeneration of garlic plants has been observed as a symptom of viral infections, with a consequent decrease in vegetative vigor (MELO FILHO et al., 2006).

Garlic plants from conventional and virus-free seeds had the highest heights when using large clove-seeds (Table 1). This is the due to the positive effect of a higher quantity of nutrient reserves available in large clove-seeds, which makes the plants more vigorous, improving plant growth and development, resulting in the higher heights (MAHADEEN, 2011). This result is consistent with those reported by Lencha and Buke (2017), who found higher heights for garlic plants grown from large clove-seeds (2.0-2.5 g) when compared to those form small clove-seeds (1.0-1.5 g).

Table 1. Mean height of conventional and virus-free garlic plants grown from different clove-seed sizes.

Plant health	Plant height (cm)	
	Clove-seed size	
	Small	Large
Conventional	51.98 Bb	54.57 Ab
Virus-free	59.01 Ba	65.46 Aa

Means followed by same uppercase letter in the rows, and lowercase in the columns, are not different by the t Student test ($p \leq 0.05$).

A mean minimum estimated plant height of 55.4 cm was found for the spacing of 7.5 cm, which was significantly lower than that found for the spacing of 12.5 cm (59.5 cm), with a stabilization trend up to the highest estimated plant height (59.6 cm) in the spacing of 15 cm (Figure 1). The higher plant heights in the wider spacings were probably due to the better light, water, and nutrient uses by the plants, which result in a higher photosynthetic activity. Similar results were reported by Muneer et al. (2017), who evaluated growth characteristics of garlic plants grown under different spacings between plants (3 to 11 cm) and found that less dense spacings result in higher plant heights.

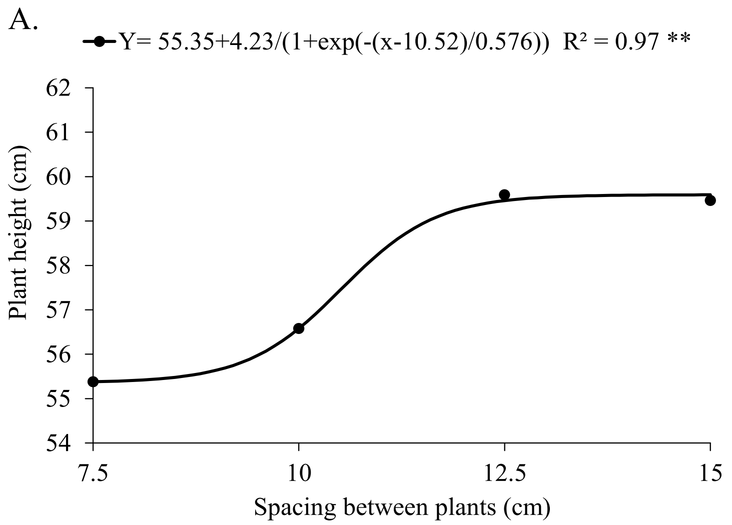

Figure 1. Plant height as a function of spacing between plants.

The mean bulb weight (MBW) of plants from large clove-seeds was higher than that of plants from small clove-seeds, regardless of the plant health status and plant spacing. The MBW of infected and virus-free plants grown from large clove-seeds were 16% and 29% higher, respectively, than those of plants grown from small clove-seeds (Table 2).

MBW gains with the use of large clove-seeds have been widely reported in studies and found in commercial crops. This can be explained by the greater carbohydrate and mineral reserves in large clove-seeds, which improves cell division and stretching, resulting in more vigorous plants that present better development and can maintain photosynthetically active leaves for longer times, which contributes to a higher photoassimilate production for the bulbs, than that in plants from small clove-seeds (MAHADEEN, 2011; MARODIN, 2014). Moreover, according to Lencha and Buke (2017), the greater nutritional reserves of large clove-seeds result in a faster establishment of emerging shoots and more efficient use of natural resources in the growth and developmental stages.

Table 2. Mean bulb weights of conventional and virus-free garlic plants grown from different clove-seed sizes in different spacings between plants.

Mean bulb weight (g planta^{-1})			
Spacing between plants (cm)	Plant health	Clove-seed size	
		Small	Large
7.5	Conventional	13.65 Bb	16.04 Ab
	Virus-free	16.58 Ba	19.10 Aa
10	Conventional	15.95 Bb	18.46 Ab
	Virus-free	22.07 Ba	26.29 Aa
12.5	Conventional	17.76 Bb	19.53 Ab
	Virus-free	27.94 Ba	37.77 Aa
15	Conventional	17.13 Bb	20.94 Ab
	Virus-free	24.59 Ba	34.84 Aa

Means followed by same uppercase letter in the rows comparing clove-seed sizes within each plant health and spacing between plants, and lowercase in the columns comparing plant health within each clove-seed size and spacing between plants, are not different by the t Student test (p≤0.05).

This result is in consistent with those reported by Nasir, Regasa and Yirgu (2017), who found an increase of 23% in MBW in commercial garlic crops as a response to the increase in clove-seed weight from 1.5-2.5 to 2.6-3.5 g. MBW is an important characteristic for the marketing of garlic and is related to the final bulb yield, since greater bulbs have higher prices in the market.

Considering the plant health within each clove-seed size and plants spacing, virus-free plants grown from small and large clove-seeds had 41% and 57% higher MBW than conventional plants, respectively (Table 2).

This higher MBW was due to the plant vigor and the vegetative growth measured by the plant height, which result in a greater net photosynthesis. Resende et al. (1999) found that the use of clove-seeds of Gigante Roxão cultivar obtained from tissue culture results in an MBW approximately 109% higher than the use of conventional clove-seeds, confirming the results found in the present work when using large clove-seeds. Similarly, Resende, Gualberto and Souza (2000) evaluated four garlic cultivars (Gigante Roxão, Gravatá, Lavínia, and Gigante Roxo) and found MBW increases of 16.4% to 95.9%.

Considering the MBW as a function of spacing between plants, the lowest estimated MBW of virus-free plants grown from large and small clove -seeds (19.1 and 16.58 g, respectively) were found for the spacing of 7.5 cm. The highest estimated MBW of virus-free plants grown from large and small clove-seeds (36.84 and 26.59 g, respectively) was found for the spacing of 15.0 cm between plants (Figure 2A). Conventional plants also showed higher MBW when using wider spacings, reaching an estimated MBW of 20.4 g when using large clove-seeds, and 17.65 g when using small clove-seeds, in the spacing of 15.0 cm between plants (Figure 2B).

The bulb weights found were, in general, higher in crops with lower populational density, which similarly affected the plant heights (Figure 1A). Increases in number of plants per unit of area increase competition for water, light, and nutrients in the crop environment, resulting lower accumulation of photoassimilates and, consequently, lower biomass accumulation in the garlic bulbs. Muneer et al., (2017) reported that garlic plants grown under low populational densities result in large bulbs due to the high availability of space for shoot growth and development and bulb expansion.

These results are consistent with those found by Marodin (2014), who evaluated virus-free (Chonan cultivar) and conventional garlic plants grown under different spacings (210, 260, 300, 360 and 390 cm^2 plant^{-1}) and found that the wider plant spacing (390 cm^2 plant^{-1}) resulted in the highest MBW for virus-free (41.6 g bulb^{-1}) and conventional (26.6 g bulb^{-1}) plants. Ahmed et al. (2017) used a spacing between rows of 30 cm to evaluated three spacings between plants (10, 15, and 20 cm) and found that the spacing of 20 cm resulted in 33% higher MBW than the spacing of 10 cm.

The total bulb yield (TBY) and commercial bulb yield (CBY) of conventional or virus-free plants grown from large clove-seeds were higher than those of plants grown from small clove-seeds, except conventional plants grown in the spacing of 12.5 cm, in which the clove-seed sizes had no effect on the TBY and CBY (Table 3). These higher TBY and CBY were due to the increase in mean bulb weight. The use of large clove-seeds resulted in higher MBW due to the higher vegetative growth (height) of the garlic plants, since the larger the leaf area, the greater the interception of radiation and, consequently, the net photosynthesis, resulting in higher dry matter accumulation (CASTELLANOS et al., 2004; AHMED et al., 2017).

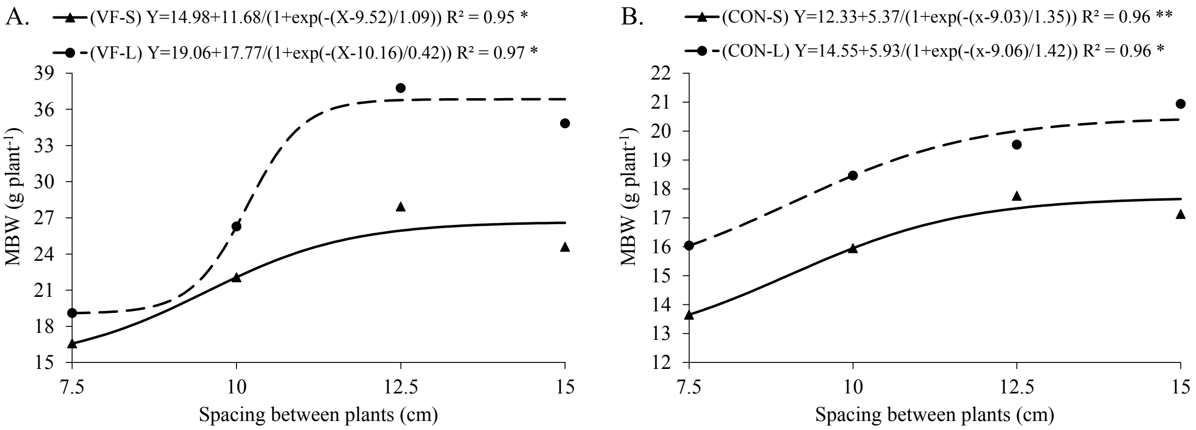

Figure 2. Mean bulb weight (MBW) of virus-free (VF) (A) and conventional (CON) (B) garlic plants grown from small (S) and large (L) clove-seeds under different spacings between plants.

Table 3. Mean total and commercial garlic bulb yields of conventional and virus-free plants grown from small and large clove-seed sizes under different spacings between plants.

Spacing between plants (cm)	Plant health	Total yield ($Mg\ ha^{-1}$)		Commercial yield ($Mg\ ha^{-1}$)	
		Clove-seed size		Clove-seed size	
		Small	Large	Small	Large
7.5	Conventional	5.88 Bb	6.98 Ab	4.60 Bb	5.99 Ab
	Virus-free	7.95 Ba	9.01 Aa	6.96 Ba	8.46 Aa
10	Conventional	5.24 Bb	6.08 Ab	4.30 Bb	5.57 Ab
	Virus-free	8.03 Ba	9.38 Aa	8.00 Ba	9.38 Aa
12.5	Conventional	4.47 Ab	5.02 Ab	3.73 Ab	4.35 Ab
	Virus-free	7.87 Ba	11.0 Aa	7.85 Ba	11.0 Aa
15	Conventional	3.69 Bb	4.59 Ab	2.95 Bb	4.05 Ab
	Virus-free	5.81 Ba	8.67 Aa	5.76 Ba	8.67 Aa

Means followed by same uppercase letter in the rows comparing the clove sizes within each plant health and spacing between plants, and lowercase letter in the columns comparing plant health within each clove-seed size and spacing between plants, are not different by the t Student test ($p \leq 0.05$).

These results are consistent with those found in other studies, which report higher garlic yields when using large clove-seeds. Gautam et al. (2014) found garlic bulb production 78% higher for clove-seeds of 1.6-2 g when compared to clove-seeds of 1-1.5 g; however, the use of clove-seeds of 3.1 g did not show significantly higher bulb production. Nasir, Regasa and Yirgu (2017) found 20% higher TBY and 24% higher CBY when using garlic clove-seeds of 2.6-3.5 g, when compared to the use of clove-seeds of 1.5-2.5 g.

Therefore, the clove-seed size is important for garlic crops, mainly during the initial crop stages, since, the nutrient reserves in the clove-seeds are partially responsible to supply the plant needs and are essential during and after the emergence, and result in higher bulb yields.

Considering the effect of the plant health within each clove-seed size and spacing between plants on the TBY and CBY, virus-free plants were superior to conventional ones (Table 3). Virus-free plants of small and large clove-seed sizes had 54% and 68%, higher mean TBY, and 83% and 87% higher CBY, respectively, than conventional plants.

Virus-free plants had, in general, higher vegetative growth and, consequently, higher MBW, which explains the higher TBY and CBY when compared to conventional plants. Ahmed et al. (2017) report that garlic bulb production is related to the plant vegetative development, and higher plants present higher bulb production potential due to the highest translocation of nutrients and photoassimilates from leaves and stems to bulbs. In addition, the presence of viruses in garlic plants usually decreases the growth index (height), number of leaves, and leaf area, probably due to metabolic disturbances, mainly photosynthesis inhibition, which affects the synthesis and transport of assimilates, and the action of plant growth regulators (VICENTE, 1979).

Similar results were found by Resende, Gualberto and Souza (2000), who evaluated four conventional and virus-free cultivars and found that plants from virus-free clove-seeds were superior to conventional ones in all production characteristics, with 46% and 63% higher mean TBY and CBY, respectively. Other studies have also reported higher productive performances for plants from virus-free clove-seeds when compared to conventional plants, with 39% (MARODIN, 2014) and 84% (RESENDE; FAQUIN; SOUZA, 2000) higher yields.

TBY and CBY of plants from virus-free seeds showed different responses to the spacing between plants within each clove-seed size. The TBY and CBY of plants from small clove-seeds increased as the spacing between plants was increased, reaching 8.22 and 8.16 Mg ha^{-1} in the spacing of 10.0 and 10.5 cm, respectively, but had a subsequent decrease, reaching 5.9 and 5.8 Mg ha^{-1}, respectively in the spacing of 15.0 cm. The TBY and CBY of plants from large clove-seeds increased as the spacing between plants was increased, reaching 11.09 and 11.07 Mg ha^{-1} in the spacing of 12.5 cm, respectively, but had a subsequent decrease, reaching 8.74 Mg ha^{-1} in the spacing of 15.0 cm (Figure 3A and 3C).

The use of low spacings between plants usually results in high mean garlic yields mainly due to the high number of bulbs per unit of area. However, despite the lowest spacings between plants used (7.5 and 10 cm) for large clove-seeds resulted in a higher competition between the plants, lowering the total bulb weight, the high MBW in the spacing of 12.5 cm compensated the low plant population, resulting in a higher TBY and CBY. Moreover, no significantly higher MBW was found for the spacing of 15 cm; thus, the use of low plant densities results in low TBY and CBY (MENGESHA; TESFAYE, 2015; VIDYA, 2015).

The use of large virus-free clove-seeds did not compensate the decrease in plant population when using spacings of 10 cm or higher, resulting in lower TBY and CBY. Thus, the spacing of 10 cm between plants result in the highest bulb yields when using small clove-seeds.

Pereira et al. (2009) evaluated plants of the Gigante Roxo garlic cultivar grown from conventional clove-seeds and found that increasing the spacing between plants from 8 to 12 cm increases the bulb yield in up to 15%; spacings between plants of 10 and 12 cm are those used by high-technology production systems in Brazil. Contrastingly, Marodin (2014) evaluated garlic plants grown under spacings of 210, 260, 300, 360 and 390 cm^2 $plant^{-1}$, in Lavras, state of Minas Geraais, Brazil, and found a linear decrease as the plant spacing was increased for virus-free (Chonan cultivar) and conventional plants.

The TBY of conventional plants decreased as the spacing between plants was increased, for both clove-seed sizes; the highest estimated TBY (5.89 and 6.79 Mg ha^{-1}) was found for the spacing of 7.5 cm, and the lowest (3.68 and 4.26 Mg ha^{-1}) for the spacing of 15.0 cm, when using small and large clove-seeds, respectively (Figure 3B).

The CBY of conventional plants grown from small and large clove-seeds was affected by the spacing between plants, with similar effect to that on the TBY; the CBY decreased as the spacing between plants was increased. The use of small and large clove-seeds resulted in the highest commercial yield, 4.60 and 5.99 Mg ha^{-1}, respectively, in the spacing of 7.5 cm, which was lower when using the spacing of 15.0 cm between plants (Figure 3D).

The conventional garlic plants had lower vegetative growth, thus, the higher MBW in the spacing of 7.5 cm was not enough to compensate the low plant density. Therefore, regardless of the clove-seed size used, the highest yield found for high populational density can be attributed to the compensatory effect of the number of plants per unit of area on individual performance of the plants (VIDYA, 2015).

These results are consistent with those found by Ahmed et al. (2017), who evaluated conventional plants of the China cultivar in Pakistan and found the highest bulb production for the spacing of 10 cm between plants, and the lowest for the spacing of 20 cm. Olfati, Najafabadi and Rabiee (2016) evaluated three spacings between rows (15, 25, and 35 cm) and found that the lowest spacing resulted in 78% higher TBY when compared to the highest. Mengesha and Tesfaye (2015) evaluated three spacings between plants (10, 15, and 20 cm) with 30 cm between rows and found 38% higher yield for the spacing of 20 cm (7.87 Mg ha^{-1}), when compared to the spacing of 10 cm (4.85 Mg ha^{-1}).

The combination of virus-free garlic, large clove-seeds, and spacing of 7.5 cm between plants presented the lowest total operational cost (Table 4). This is due to the labor costs and the clove-seed cost, since the price of large virus-free garlic clove-seeds is higher, and the need for a higher quantity of clove-seeds (500.000 clove-seeds ha^{-1}).

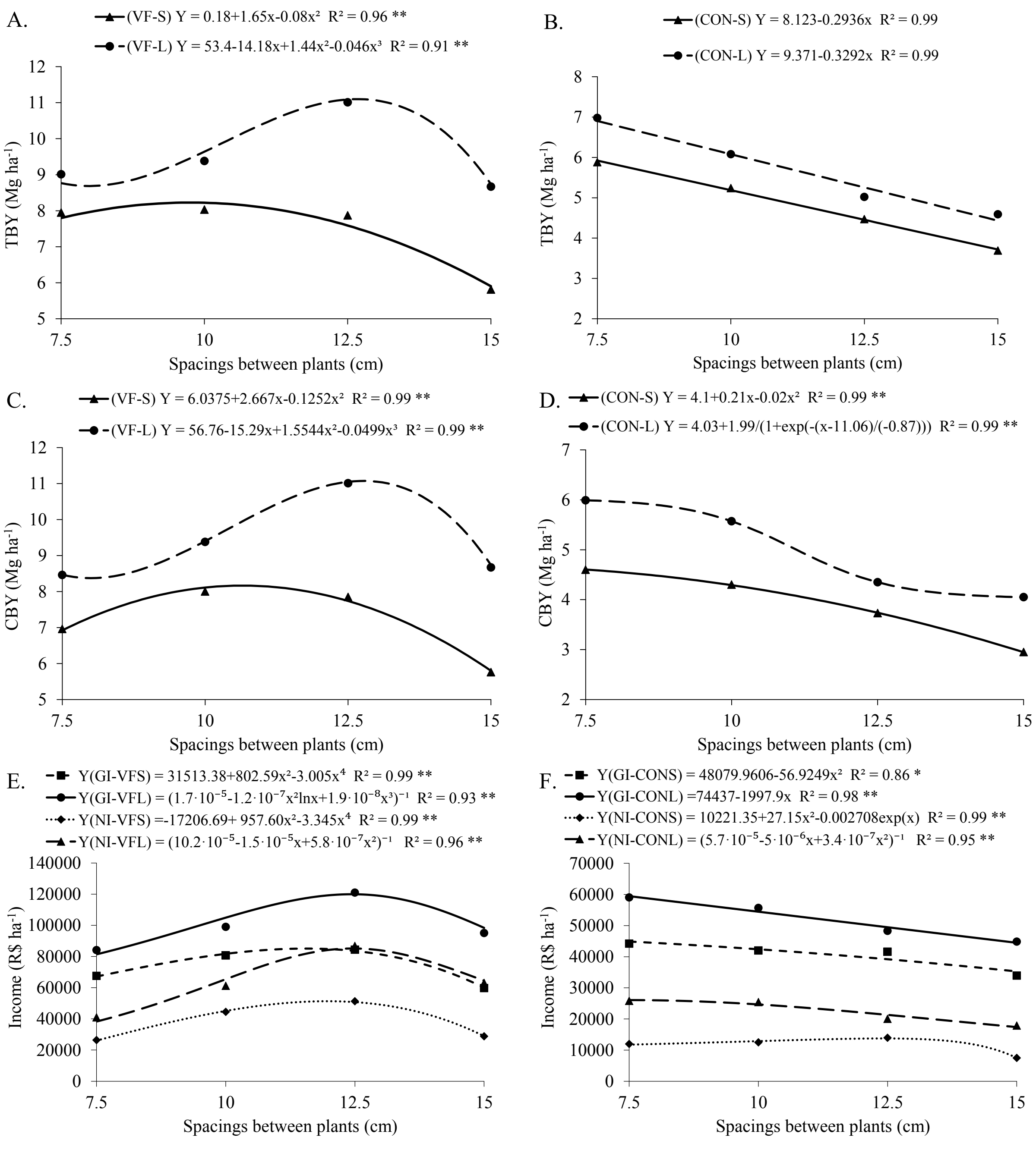

Figure 3. Total bulb yield (TBY) of virus-free (VF) (A), and conventional (CON) (B) garlic plants; commercial bulb yield (CBY) of VF (C), and CON (D) garlic plants; gross and net income of VF (E) and CON (F) garlic plants grown from small (S) and large (L) clove-seed sizes under different spacings between plants.

The use of large clove-seeds resulted in a higher gross and net income for conventional and virus-free crops than the use of small clove-seeds. Considering the differences in plant health within each clove-seed size and spacing between plants, the gross and net income from garlic bulbs from virus-free plants were superior than those from conventional ones (Table 5). The difference in net income between health and conventional plants ranged from R$ (BRL) 14,391.74 to R$ (BRL) 66,739.97, and the difference in net income between clove sizes ranged from R$ (BRL) 6,076.87 and R$ (BRL) 35,476.64 ha^{-1}.

Despite the use of virus-free seeds and large clove-seeds had a mean total operational cost 22% and 4% higher (Table 4), respectively, when compared to the use of conventional and small clove -seeds, the higher yields of these superior seeds compensated the increases in costs.

Castellanos et al. (2004) found higher production costs when using large clove-seeds (10 g clove-seed^{-1}), but higher gross income (US$

25,335.00 ha^{-1}). However, the highest profit (US$ 13,461.00) was obtained when using seeds of 3.6 and 6.5 g clove-seed^{-1}, since the use of larger seeds require higher quantities of seeds, which increases production costs; thus, despite obtaining the highest gross income, the net income is lower.

The gross and net income was affected by the spacing between plants; they increased as the spacing between plants was increased, reaching the estimates of R$ (BRL) 119,958.00 and R$ (BRL) 85,151.00 ha^{-1}, respectively, when using virus-free plants grown from large clove-seeds under the spacing of 12.5 cm. The gross and net income also increased as the spacing between plants was increased up to the spacing of 12.0 cm when using small clove-seeds, reaching the estimates of R$ (BRL) 85,100.00 and R$ (BRL) 51,322.00 ha^{-1} (Figure 3E).

Table 4. Total operational cost of conventional and virus-free garlic crops grown from small and large clove-seed sizes (CSS) under different spacings between plants (SBP).

Total operational cost (TOC)							
Plant health	CSS	SBP	Costs in R$ (BRL) ha^{-1}				
			Inputs*	Fertilizers	Labor	Seeds	TOC
Virus-free	Small	7.5	9726.20	5676.50	7824.00	18000.00	41226.70
		10	9726.20	5676.50	7352.70	13500.00	36255.40
		12.5	9726.20	5676.50	6881.50	10800.00	33084.20
		15	9726.20	5676.50	6567.40	9000.00	30970.10
	Large	7.5	9726.20	5676.50	7824.00	20000.00	43226.70
		10	9726.20	5676.50	7352.70	15000.00	37755.40
		12.5	9726.20	5676.50	6881.50	12000.00	34284.20
		15	9726.20	5676.50	6567.40	10000.00	31970.10
Conventional	Small	7.5	9726.20	5676.50	7824.00	9000.00	32226.70
		10	9726.20	5676.50	7352.70	6750.00	29505.40
		12.5	9726.20	5676.50	6881.50	5400.00	27684.20
		15	9726.20	5676.50	6567.40	4500.00	26470.10
	Large	7.5	9726.20	5676.50	7824.00	10000.00	33226.70
		10	9726.20	5676.50	7352.70	7500.00	30255.40
		12.5	9726.20	5676.50	6881.50	6000.00	28284.20
		15	9726.20	5676.50	6567.40	5000.00	26970.10

*Inputs include irrigation equipment, agrochemicals, and electrical energy.

Table 5. Mean gross and net income of conventional and virus-free plants grown from small and large clove-seed sizes under different spacings between plants (SBP).

SBP (cm)	Plant health	Gross income R$ (BRL) ha^{-1}		Net income R$ (BRL) ha^{-1}	
		Clove-seed size		Clove-seed size	
		Small	Large	Small	Large
7.5	Conventional	44,184.81 Bb	59,042.26 Ab	44,184.81 Bb	59,042.26 Ab
	Virus-free	67,576.55 Ba	84,135.69 Aa	67,576.55 Ba	84,135.69 Aa
10	Conventional	41,985.00 Bb	55,660.08 Ab	41,985.00 Bb	55,660.08 Ab
	Virus-free	80,694.73 Ba	98,982.25 Aa	80,694.73 Ba	98,982.25 Aa
12.5	Conventional	41,618.50 Bb	48,295.37 Ab	41,618.50 Bb	48,295.37 Ab
	Virus-free	84,358.70 Ba	121,035.34 Aa	84,358.70 Ba	121,035.34 Aa
15	Conventional	33,934.38 Bb	44,848.35 Ab	33,934.38 Bb	44,848.35 Ab
	Virus-free	59,730.72 Ba	95,089.79 Aa	59,730.72 Ba	95,089.79 Aa

Means followed by same uppercase letter in the rows comparing the clove sizes within each plant health and spacing between plants, and lowercase letter in the columns comparing plant health within each clove-seed size and spacing between plants, are not different by the t Student test ($p \leq 0.05$).

However, conventional plants had different dynamics; the gross and net income was affected by the spacings between plants, but with decreases as the spacing between plants was increased when using large clove-seeds under the spacing of 7.5 cm, reaching the estimates of R$ (BRL) 58,832.00 and R$ (BRL) 25,815.00 ha^{-1}, respectively. Moreover, the gross income decreased as the spacing between plants was increased when using small clove-seeds under the spacing of 7.5 cm, reaching the estimates of R$ (BRL) 44,887.00. However, the net income had a slight increase for spacings higher than 7.5, reaching the estimate of R$ (BRL) 11,743.00 in the spacing of 12.5 cm (Figure 3F).

The garlic crops presented favorable results for several economic efficiency indexes. The spacings that resulted in the highest total and commercial yields provided, in general, the highest profits. Thus, the combination of virus-free seeds, large clove-seeds, and spacings between plants of 12.5 cm (300000 plants ha^{-1}) was the treatment with higher commercial yield (11 Mg ha^{-1}) and provided the highest net income, R$ (BRL) 85,151.00 ha^{-1}.

These results were consistent with those found by of Castellanos et al. (2004), who found that the density of 600000 plants ha^{-1} resulted in the highest yields and production cost, but provided a profitability 15% lower than the use of a populational density of 300000 plants $ha^{-1.}$ This is due to the production of large bulbs, i.e., with higher market value, which compensate the low yield of low populational density, and the increase in production cost of crops with higher densities, due to higher cost with seeds.

Therefore, the garlic crops were profitable when considering the costs involved and the economic return. Moreover, the use of virus-free garlic plants for commercial production should be monitored; despite these virus-free seeds have a high productive potential and economic return, they can undergo degeneration and cause decrease in the production when not managed correctly, mainly in successive crops.

CONCLUSIONS

The garlic crops grown using virus-free clove-seeds and large clove-seeds presented the highest vegetative growth, yield, and economic return.

The combination of virus-free clove-seeds, large clove-seeds, and spacing between plants of 12.5 cm resulted in the highest net income, R$ (BRL) 85,151.00 ha^{-1}.

The use of large clove-seeds with spacing between plants of 7.5 cm is recommended for the growth of conventional garlic plants.

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