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Performance of onion cultivars as a function of spacing between plants

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Key words:
Allium cepa L.
planting density
classification of bulbs
yield

A B S T R A C T
The objective of this study was to evaluate the performance of onion cultivars as a function of the spacing between plants. The experimental design was a complete randomized block in a 3 x 4 factorial scheme, with four replicates. The treatments were composed of the combination between three onion cultivars (Vale Ouro IPA 11, Serena and Rio das Antas) and four plant spacings (3, 6, 8 and 10 cm). The evaluated characteristics were total, marketable and unmarketable yield of bulbs, percentages of bulbs in classes 1, 2, 3 and 4, bulb mean weight, bulb dry weight. In onion cultivation, the cultivars Rio das Antas and Serena are the most indicated, with the highest marketable yields at 6 and 3 cm spacings between plants, respectively. The cultivar Vale Ouro IPA 11 presented higher marketable yield for the spacing of 5 cm between plants.

Palavras-chave:
Allium cepa L.
densidade de plantio
classificação de bulbos
rendimento

Desempenho de cultivares de cebola em função do espaçamento entre plantas

R E S U M O
Objetivou-se neste trabalho avaliar o desempenho de cultivares de cebola em função do espaçamento entre plantas. O delineamento experimental utilizado foi em blocos casualizados completos em esquema fatorial 3 x 4 com quatro repetições. Os tratamentos foram constituídos da combinação de três cultivares de cebola (Vale Ouro IPA 11, Serena e Rio das Antas) e quatro espaçamentos entre plantas (3, 6, 8 e 10 cm). As características avaliadas foram: produtividades total, comercial e não comercial de bulbos, porcentagens de bulbos das classes 1, 2, 3 e 4, massa média de bulbos, massa seca de bulbos. Nos cultivos de cebola de forma adensados, as cultivares Rio das Antas e Serena são as mais indicadas, com as maiores produtividades comerciais, respectivamente nos espaçamentos de 6 e 3 cm entre plantas. A cultivar Vale Ouro IPA 11 apresentou maior produtividade comercial no espaçamento de 5 cm entre plantas.

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Introduction

In Brazil, onion (*Allium cepa* L.) is considered as the third most important vegetable in economic value, only surpassed by tomato and potato, with planted area in 2016 of 56,169 ha, which corresponds to production of 1,563,986 t and mean yield of 27.8 t ha^{-1}. In the northeast region, the states of Pernambuco and Bahia are the largest producers, responsible for 97.9% of the regional production, with mean yields of 24.9 and 29.8 t ha^{-1}, respectively (IBGE, 2017).

Hybrid cultivars have aroused the interest of onion growers due to the agronomic superiority in comparison to other cultivars of open pollination (May et al., 2007). The use of hybrid seeds combined with other planting technologies, such as drip irrigation, fertigation and dense cultivation, has contributed to allowing the production in large areas.

Spacing can be chosen according to the tolerance of the cultivar to dense cultivation, climatic conditions of the region and type of bulb required by the market (Longo, 2009). Increment in planting density can improve the exploitation of the environment and cultivar, leading to increase of yield. Hence, it is important to establish an optimal population, which maximizes the exploitation of the production factors, ensuring higher yield (Baier et al., 2009).

In this context, various studies carried out in Brazil demonstrate that planting density is a factor of extreme importance to obtain high production. Menezes Júnior & Vieira Neto (2012) and Harms et al. (2015) proved that increase in density by reducing planting spacing leads to increase in total yield of bulbs.

In the Rio Grande do Norte state, IPA 11 has been the most planted onion cultivar, at density of 400.000 plants ha^{-1}, with mean yields from 35 to 40 t ha^{-1}. More recently, with the introduction of onion hybrids, some producers have employed the direct seeding system with higher planting density, using populations from 800 to 1,000 thousand plants ha^{-1}. However, in practice the increments in yield have not been expressive. Onion in these municipalities is cultivated using a drip irrigation system, in beds with eight rows at fixed spacing (10 cm), and planting density is increased by reducing the spacing between plants.

Since it is a new methodology, some adjustments are needed because, when sowing density increases, factors such as competition for water, light and nutrients are altered, requiring local studies, especially using the new hybrids, which are mostly introduced from other regions and do not always adapt to the local production system. In this context, Rebouças et al. (2008) report that the choice on the planting system, seed and spacing or sowing density to be used may vary from one producing region to another, due to various factors. These factors include the planting period, which will determine luminosity (intensity and duration), and temperature, which in turn exerts direct influence on bulbification and maturation; availability of machines, and availability and costs of labor, besides the type of soil, weed control method and lastly the method of irrigation and type of planting machine. However, according to Ferreira (2000), some onion cultivars allow the increment in planting density, while for others such procedure increases the production of smaller bulbs.

Therefore, this study aimed to evaluate the performance of onion cultivars as a function of spacing between plants.

Material and Methods

The experiment was carried out in the period from August to November 2015, at the Rafael Fernandes Experimental Farm, of the Federal Rural University of the Semi-Arid Region (UFERSA), located in the district of Alagoinha, municipality of Mossoró, RN, Brazil (5° 0333.49 S; 37° 253.60 W), in soil classified as typic dystrophic Red Argisol (Rêgo et al., 2016). Soil chemical analysis in the 0-20 cm layer showed the following results according to methodologies of Tedesco et al. (1995): pH (H_2O) = 6.01; EC dS m^{-1} = 0.05; P mg dm^{-3} = 15.59; K^+ mg dm^{-3} = 65.55; Na^+ mg dm^{-3} = 3.00; Ca^{2+} $cmol_c$ dm^{-3} = 0.84; Mg^{2+} mol_c dm^{-3} = 0.21; Al^{3+} $cmol_c$ dm^{-3} = 0.00.

According to Köppen's classification, the local climate is BSwh, dry and very hot, with two seasons: a dry one, which generally comprehends the period from June to January, and a rainy one, from February to May (Carmo Filho et al., 1991).

The experiment was set in complete randomized blocks in 3 x 4 factorial scheme, with four replicates. Treatments consisted in the combination of three onion cultivars (Vale Ouro IPA 11, Rio das Antas and Serena) and four planting spacings (3, 6, 8 and 10 cm). The experimental unit comprised one bed containing eight plant rows spaced by 10 cm, 3 cm between plants and 1 m wide, with number of plants varying according to the spacing. The six central rows were used for evaluations, disregarding two plants on each end of the rows.

Soil tillage consisted in plowing, harrowing and raising of beds. Chemical fertilization at planting was performed based on soil analysis and on the quantity of nutrients used by the onion producers of the region, by applying only phosphorus, at dose of 150 kg ha^{-1} of P_2O_5, in the form of triple superphosphate.

A drip irrigation system was used, with four hoses per bed, spaced by 20 cm, and pressure-compensating drippers spaced by 30 cm, with mean flow rate of 1.5 L h^{-1}. Irrigations were daily applied, and water depths were determined based on crop evapotranspiration (Allen et al., 1998).

The experiment was installed in the field by direct seeding, manually placing 3 to 4 seeds per hole, and thinning at 21 days after sowing (DAS), leaving only one plant per hole.

Top-dressing fertilizations were weekly applied via fertigation in 12 applications, starting at 25 and ending at 89 DAS, providing 180 kg ha^{-1} of N, 280 kg ha^{-1} of K_2O and 150 kg ha^{-1} of P_2O_5, in the forms of urea, potassium chloride, MAP, calcium nitrate and potassium nitrate. As source of micronutrients, 1 kg ha^{-1} of Rexolin® was applied (11.6% of K_2O, 1.28% of S, 0.86% of Mg, 2.1% of B, 0.36% of Cu, 2.66% of Fe, 2.48% of Mn, 0.036% of Mo and 3.38% of Zn). Phytosanitary control and the other cultivation practices were performed according to the recommendations adopted in the region for the onion crop.

When nearly 70% of the plants were lodged, irrigation was suspended and the curing process started. After 20 days, plants were harvested and topped, which consisted in cutting the leaves from 2 to 3 cm of the bulb and cutting the roots. Then, bulbs were transported to the Laboratory of the Plant

Science Department (DCV) of the UFERSA, to evaluate the following characteristics:

- Marketable yield of bulbs (t ha^{-1}): determined by the total weight of bulbs with diameter > 35 mm, without defects;
- Unmarketable yield of bulbs (t ha^{-1}): obtained by the total weigh of bulbs with diameter < 35 mm, and/or double bulbs or with defects;
- Total yield of bulbs (t ha^{-1}): obtained by summing marketable and unmarketable yields;
- Classification of bulbs: performed based on bulb transverse diameter according to norms of the Ministry of Agriculture, Livestock and Supply (Brasil, 1995) – class 1 (diameter < 35 mm); class 2 (diameter 35-49 mm); class 3 (diameter 50-74 mm); class 4 (diameter 75-90 mm); and class 5 (diameter > 90 mm);
- Bulb mean weight (g): obtained by dividing the marketable yield by the number of marketable bulbs harvested in the plot, after curing and topping;
- Bulb dry weight (g): 10 bulbs per plot were dried in forced air circulation oven at 65 °C, until constant weight.

The data were subjected to analysis of variance and, when there was significant effect for the qualitative factor (cultivars), means were compared by Tukey test at 0.05 probability level, and regression analysis was applied for the quantitative factor (spacings), using the software Sisvar, version 5.6 (Ferreira, 2014).

Results and Discussion

Analysis of variance revealed significant interaction between cultivars and spacings between plants for all characteristics evaluated, except dry weight of bulbs (Table 1).

The total yield as a function of spacing between plants showed a quadratic behavior (Figure 1A). Maximum estimated values were 81.85, 103.08 and 101.66 t ha^{-1} at spacings of 4.4, 5.7 and 3.0 cm, for the cultivars IPA 11, Rio das Antas and Serena, respectively. Marketable yield exhibited a similar response, with maximum estimated values of 77.11, 101.80 and 97.40 t ha^{-1}, respectively, at the spacings of 5.3, 5.9 and 3.0 cm between plants for the cultivars IPA 11, Rio das Antas and Serena, respectively (Figure 1B).

The high yields obtained in this experiment were possibly due to the favorable climatic conditions, low variation of temperature and humidity, absence of rainfall, low incidence of pests and diseases, and use of adequate technologies

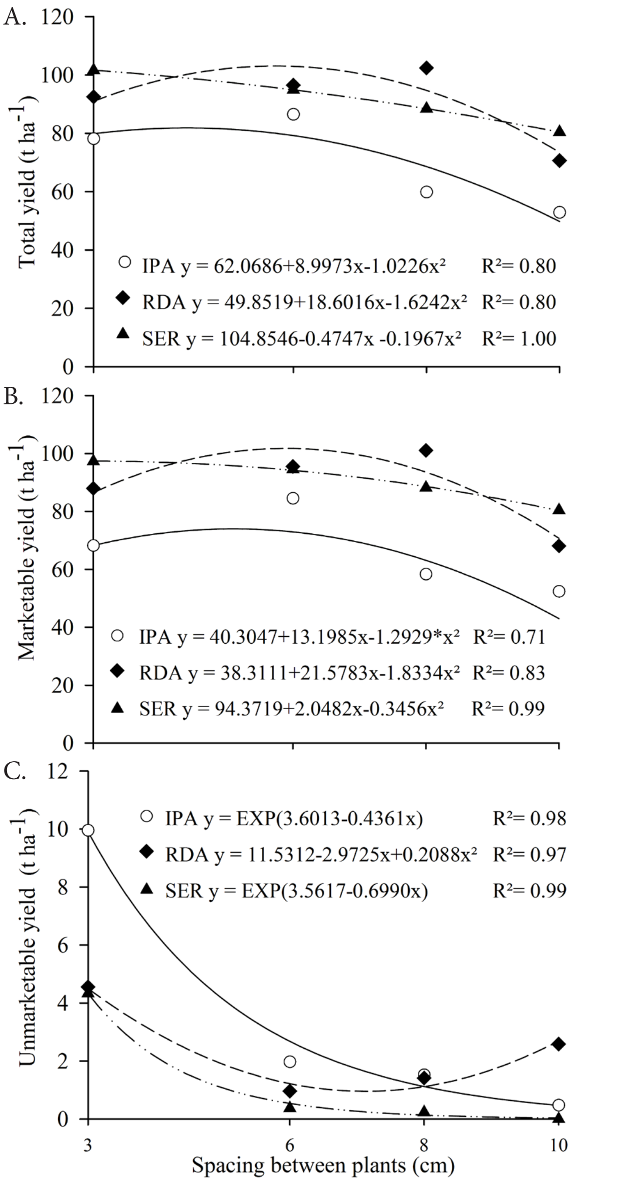


Figure 1. Total yield (A), marketable yield (B) and unmarketable yield (C) of the onion cultivars IPA 11 (IPA), Rio das Antas (RDA) and Serena (SER) as a function of spacing between plants

such as drip irrigation, fertigation, direct seeding and dense cultivation. All of these factors promoted better conditions for plant development, contributing to yield higher than the mean of the country (27.84 t ha^{-1}) and Northeast region (32.72 t ha^{-1}) (IBGE, 2017).

Total and marketable yields were higher than those reported by Henriques et al. (2014), who studied two onion cultivars

Table 1. Analysis of variance for total yield (TY), marketable yield (MY), unmarketable yield (UY), percentage of bulbs (class 1, class 2, class 3 and class 4), bulb mean weight (BMW), bulb dry weight (BDW) as a function of onion cultivars and spacings between plants

S.V.	D.F.	TY	MY	UY	Class 1	Class 2	Class 3	Class 4	BMW	BDW
		Mean square								
Blocks	3	3.91^{ns}	3.76^{ns}	0.03^{ns}	0.01^{ns}	0.40^{ns}	2.35^{ns}	1.88^{ns}	16.10^{ns}	0.38^{ns}
Cultivars (C)	2	2488.73**	2902.71**	20.20**	46.00**	1598.92**	603.66**	4146.47**	5975.33**	64.03**
Spacings (S)	3	1507.32**	1288.02**	81.71**	105.39**	5366.69**	1836.93**	3470.23**	12097.33**	4.05**
C x S	6	284.32**	279.48**	10.85**	22.04**	46.57**	1093.80**	625.90**	323.71**	0.57^{ns}
Error	33	2.87	2.45	0.07	0.07	0.54	1.44	1.08	46.53	0.36
CV (%)		2.02	1.92	11.77	9.73	3.84	2.13	4.88	7.34	8.07

^{ns}Not significant; **Significant at 0.01 probability level by F test

(IPA 11 and Bela Dura) at different spacings between plants under the conditions of Mossoró, RN, and found maximum values for total and marketable yields of 30.48 and 24.74 t ha^{-1} at the spacings of 3 and 5 cm, respectively. Nevertheless, Baier et al. (2009) worked with three planting densities (50, 75 and 100 plants m²) in the onion crop and obtained maximum yield of 92.2 t ha^{-1} at the highest density studied (100 plants m^{-2}).

Among the cultivars, the hybrids Rio das Antas and Serena were superior to the cultivar IPA 11, at all spacings between plants, for total and marketable yields (Figure 1A e B). This result reinforces the superiority of the hybrids, especially in dense cultivation. Such superiority is possibly related to vigor, purity and high genetic load of hybrid seeds, promoting high yields, when cultivated under adequate management. Vilas Boas et al. (2011) and Faria et al. (2012) observed higher yields of the hybrids compared with the cultivars.

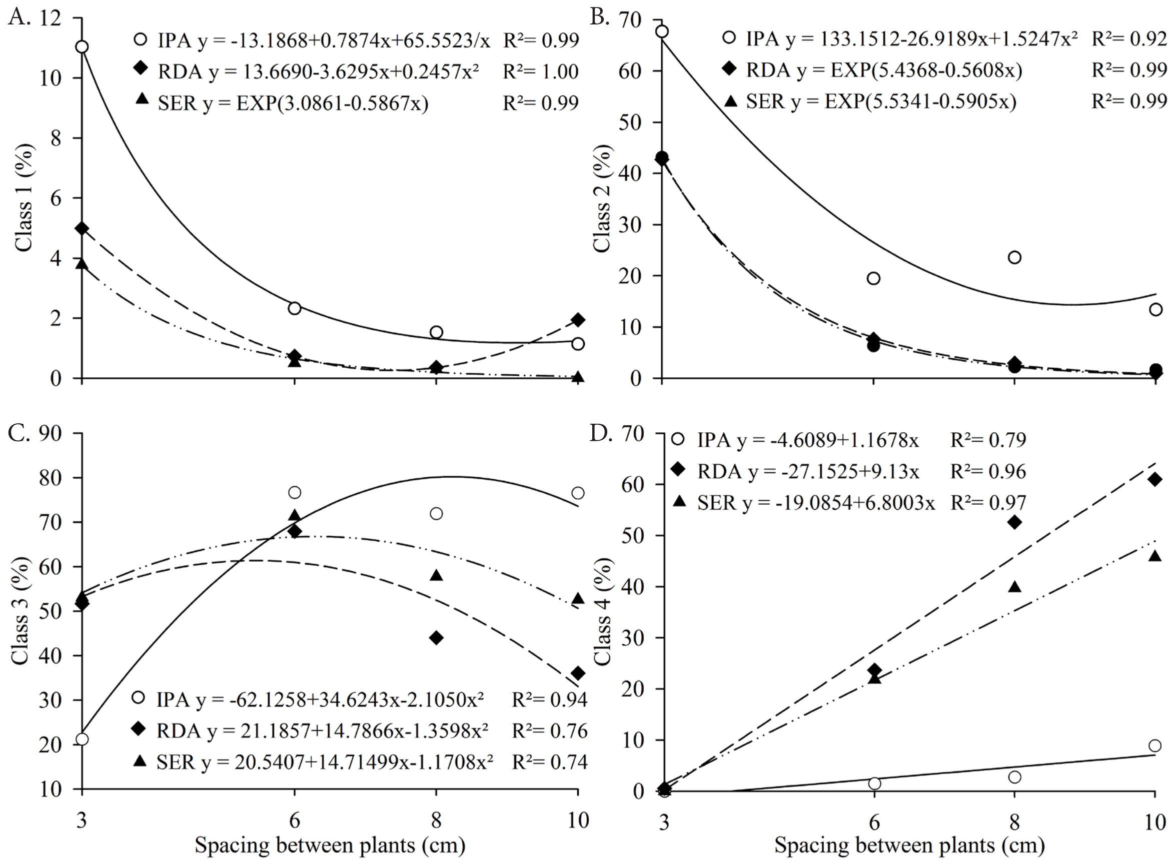
Increase in spacing between plants reduced the yield of unmarketable bulbs. Such reduction was approximately 97, 58 and 100% between the smallest (3 cm) and largest spacing (10 cm), respectively for the cultivars IPA 11, Rio das Antas and Serena (Figure 1C). Reduction in unmarketable yield is a desirable characteristic for the onion producer, since this type of bulb has low commercial value. Reduction of unmarketable bulbs with the increase in spacing was also found by Henriques et al. (2014).

Among the cultivars, except at spacing of 10 cm, IPA 11 was superior to the others for unmarketable yield (Figure 1C). The superiority of Rio das Antas at spacing of 10 cm is due to the high production of double bulbs, which probably resulted from its higher susceptibility to this physiological disorder, and the increase in spacing may also have contributed to this behavior. At high planting densities, there is lower occurrence of double bulbs, because of the greater competition between plants (May et al., 2007).

The percentages of bulbs in classes 1 and 2 decreased as the spacing between plants increased. For class 1, the maximum values estimated were 11.02, 4.99 and 3.76%, obtained at spacing of 3 cm between plants, respectively for the cultivars IPA 11, Rio das Antas and Serena (Figure 2A). For class 2, the maximum values estimated were 66.11, 42.70 and 43.06%, obtained at spacing of 3 cm between plants, respectively for the cultivars IPA 11, Rio das Antas and Serena (Figure 2B).

Increasing the spacing between plants from 3 to 10 cm reduced the percentage of bulbs class 1 by 88.72, 61.02 and 98.20% and class 2 by 75.17, 98.03 and 98.39% respectively, for the cultivars IPA 11, Rio das Antas and Serena. This response is probably due to the lower competition between plants for production factors such as water, light, nutrients, CO_2 and oxygen, caused by the increase in spacing (Zanine & Santos, 2004). Onion plants grown at smaller spacings tend to reduce fresh weight and diameter of bulb. Menezes Júnior & Vieira Neto (2012) observed a reduction of 97.4% in the yield of bulbs class 2 with the reduction in density from 600 to 200.000 plants ha^{-1}. Henriques et al. (2014) also observed a reduction of 23.4% as the spacing increased from 3 to 10 cm between plants, confirming the results found in the present study.

The cultivar IPA 11 produced more percentage of bulbs classes 1 and 2 compared with the others, except at the spacing of 10 cm for bulbs class 1, for which Rio das Antas was superior



Class 1 - Diameter < 35 mm; Class 2 - Diameter between 35-49 mm; Class 3 - Diameter between 50-74 mm; Class 4 - Diameter between 75-90 mm

Figure 2. Percentage of bulbs class 1 (A), class 2 (B), class 3 (C) and class 4 (D) of the onion cultivars: IPA 11 (IPA), Rio das Antas (RDA) and Serena (SER) as a function of spacing between plants

(Table 2). This demonstrates that the cultivar IPA 11 does not tolerate much high planting density, which leads to increment in the percentage of smaller bulbs.

The percentage of bulbs class 3 responded quadratically to the increase in spacing. The maximum values estimated were 80.25, 61.38 and 66.77%, obtained at spacings of 8.2, 5.4 and 6.3 cm, respectively for IPA 11, Rio das Antas and Serena (Figure 2C). At the largest spacings, the lower intraspecific competition for production factors led the plant to produce bulbs with greater diameter. When planting density increases, there is an increment in the competition between plants for natural resources such as light, water, CO_2, O_2 and mineral nutrients, thus altering the patterns of bulbification of the cultivars (Mascarenhas, 1993).

The cultivar IPA 11 produced more percentage of bulbs class 3 at spacings of 6, 8 and 10 cm, compared with the others. However, it showed the lowest yields, indicating low capacity to tolerate dense planting. At the spacing of 3 cm, Rio das Antas and Serena were superior to IPA 11 (Table 2). The cultivar IPA 11 showed higher percentage of bulbs class 3.

For the percentage of bulbs class 4, the cultivars showed a linear response to the increment in spacing between plants. Maximum values were 7.06, 64.14 and 48.91% at spacing of 10 cm, respectively for IPA 11, Rio das Antas and Serena (Figure 2D). Reduction in the number of plants per area unit leads to a lower competition between plants for production factors such as water, light, CO_2, O_2 and nutrients, promoting greater height and number of leaves, consequently, larger photosynthetic area and greater accumulation of photosynthates, allowing increment in bulb diameter (Menezes Júnior & Vieira Neto, 2012).

The cultivars Rio das Antas and Serena exhibited the highest percentages of bulbs class 4 (Table 2). The good tolerance, high vigor and hybrid genetic pattern possibly contributed to these results according to Henriques et al. (2014). The cultivar Rio das Antas, at spacings of 8 and 10 cm, was superior to the others regarding the percentage of bulbs class 4, not differing from Serena at the spacing of 6 cm (Table 2). IPA 11 showed lower performance compared with the others, possibly for not being adapted to dense planting.

Bulb mean weight responded quadratically to the increase in the spacing between plants, for all cultivars (Figure 3A). The maximum values estimated were 87.67, 123.78 and 139.74 g $plant^{-1}$, obtained at spacings of 8.8, 9.3 and 10 cm, respectively for the cultivars IPA 11, Rio das Antas and Serena. Increase in bulb mean weight with the increment in spacing has also been found by Baier et al. (2009) and Menezes Júnior & Vieira Neto (2012), who described that the higher bulb fresh weight obtained at the lowest densities is probably related to the larger area explored by the roots and lower competition for production factors such as water, light, nutrients, CO_2 and O_2.

The cultivar Serena obtained higher bulb mean weight compared with IPA 11 at all spacings, but did not differ from Rio das Antas, except at spacing of 10 cm (Table 3). It is evident

Table 3. Bulb mean weight (BMW) and bulb dry weight (BDW) of onion as a function of cultivars and spacings between plants

Cultivars	BMW (g $plant^{-1}$) Spacings (cm)				BDW (g $plant^{-1}$)
	3	6	8	10	
IPA 11	35.89 b	78.43 b	83.30 b	86.79 c	9.57 a
Rio das Antas	52.51 a	98.86 a	126.62 a	120.86 b	7.21 b
Serena	52.78 a	108.06 a	130.78 a	139.56 a	5.59 c

*Means followed by the same letter in the column do not differ by Tukey test at 0.05 probability level

Table 2. Percentage of onion bulbs class 1, class 2, class 3 and class 4 as a function of cultivars and spacings between plants

Cultivars	Spacings (cm) 3	6	8	10	Spacings (cm) 3	6	8	10
	Class 1* (%)				Class 2 (%)			
IPA 11	12.72 a	2.27 a	2.53 a	0.90 b	66.44 a	19.49 a	23.58 a	13.45 a
Rio das Antas	4.91 b	0.99 b	1.37 b	3.65 a	42.76 b	7.61 b	2.93 b	0.95 b
Serena	4.25 c	0.38 c	0.26 c	63.14 b	42.92 b	6.36 b	2.22 b	1.67 b
	Class 3 (%)				Class 4 (%)			
IPA 11	20.83 b	76.75 a	71.17 a	76.73 a	0.0 a	1.47 c	2.71 c	8.91 c
Rio das Antas	51.74 a	67.78 c	43.58 c	35.43 c	0.57 a	23.84 a	52.10 a	59.96 a
Serena	52.82 a	71.40 b	57.78 b	52.59 b	0.00 a	23.60 a	39.73 b	45.73 b

Means followed by the same letter in the column do not differ by Tukey test at 0.05 probability level
* Class 1 - Diameter < 35 mm; Class 2 - Diameter between 35-49 mm; Class 3 - Diameter between 50-74 mm; Class 4 - Diameter between 75-90 mm

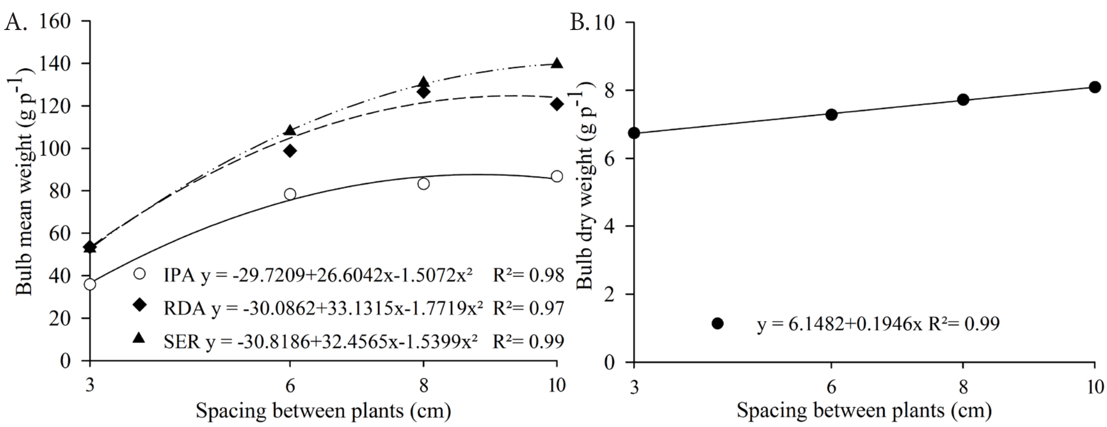


Figure 3. Bulb mean weight (A) for the onion cultivars IPA 11 (IPA), Rio das Antas (RDA) and Serena (SER) and bulb dry weight (B), as a function of spacing between plants

the superiority of the hybrids (Rio das Antas and Serena) in comparison to the cultivar of open pollination (IPA 11). Rodrigues et al. (2006) found that onion hybrids are superior to cultivars of open pollination for both yield and bulb mean weight. In study carried out by Rebouças et al. (2008), the hybrid Mercedes was superior to the cultivar Serrana, obtaining an increment of about 18.8% in the mean weight of marketable bulbs, with the increase in planting density, corroborating the results found.

Increase in spacing between plants promoted linear increment in bulb dry matter, and the highest mean values were obtained at the largest spacings. There was an increase of 16.84% between the smallest and largest spacing (Figure 3B). Increment in bulb dry weight with the increase in spacing has also been observed by other authors (Cecílio Filho et al., 2009; Henriques et al., 2014).

Among the cultivars, IPA 11 was superior to the others, obtaining mean value of bulb dry weight of 9.57 g plant^{-1} (Table 3). Dry weight is an important factor of quality, especially for the industry of processing. The higher the dry weight content, the lower the amount of energy necessary for the dehydration process (Soares et al., 2004).

Conclusions

1. In dense onion cultivation, the cultivars Rio das Antas and Serena are more indicated, with the highest marketable yields at spacings of 5.9 and 3 cm between plants, respectively.

2. The cultivar Vale Ouro IPA 11 showed higher marketable yield at spacing of 5 cm between plants.

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