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Productive and physiological performance of lettuce cultivars at different planting densities in the Brazilian Semi-arid region

Hozano de Souza Lemos Neto[1*], Marcelo de Almeida Guimarães[1], Jean Paulo de Jesus Tello[2], Rosilene Oliveira Mesquita[1], Júlio César do Vale[1] and Benedito Pereira Lima Neto[1]

[1]Department of Fitotecnia, Federal University of Ceará (UFC), Brazil.
[2]Department of Fitotecnia, Federal University of Viçosa (UFV), Brazil.

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In regions of high temperature, production and quality in the lettuce is reduced. This requires finding of cultivars that are more adapted to such conditions and adjust the planting density for each cultivar. Consequently, the aim of this study was to evaluate the productive and physiological performance of lettuce cultivars at different planting densities under semi-arid conditions. The experiment was carried out at the Horticulture Teaching Garden of the Federal University of Ceará in Fortaleza, in a randomised block design with four replications, with the treatments arranged in a 4 × 4 factorial scheme. The first factor consisted of four lettuce cultivars (Red Salad Bowl, Salad Bowl Green, Mimosa Green Salad Bowl and Crespa Lollo Bionda) and the second factor of four planting densities (0.20 × 0.20 m, 0.25 × 0.25 m, 0.20 × 0.25 m 0.25 × 0.30 m between plants and rows). The characteristics of the lettuce such as qualitative (age at bolting and flowering, and state of health - pests and diseases), quantitative (plant height and diameter, fresh and dry commercial weight, fresh and dry non-commercial weight, and total fresh and dry weight), and physiological (gas exchange) were evaluated. The Salad Bowl Green and Mimosa Green Salad Bowl cultivars displayed average tolerance to bolting (63 days after sowing, DAS) and late flowering (95 DAS). 'Salad Bowl Green' had the highest total fresh and dry weight. For density, greater individual plant production was seen at 0.25 × 0.30 m; greater productivity of commercial fresh weight and total fresh weight was seen at 0.20 × 0.20 m for all cultivars. 'Salad Bowl Green' is the most promising for cultivation under semi-arid conditions when grown at lower densities.

Key words: *Lactuva sativa* L., early bolting, productivity, dry weight, gas exchange.

INTRODUCTION

Lettuce is one of the most consumed and marketed leafy vegetables in Brazil. Due to being highly perishable, and having little resistance to transportation and post-harvest handling, its production is concentrated close to urban centres (Souza et al., 2008).

Being a temperate crop it adapts better to warm temperatures, so that in tropical regions with high temperatures and luminosities, cultivation is hampered. This is due to the stimulation of early bolting and acceleration of the plant cycle, preventing expression of the maximum yield potential (Bezerra Neto et al., 2005; Guimarães et al., 2014). The demonstration of this potential depends on the genetic constitution (cultivar) and the conditions of soil and climate to which it is subjected.

There are several lettuce cultivars available on the market. It is therefore essential to find the one best suited to a given growing condition. As a result, the cultivar being used is important to the success of the adopted cropping system (Lima et al., 2004; Guimarães et al., 2011; Blind and Silva Filho, 2015).

In recent decades, with the advances in genetic improvement, companies have gradually launched onto the market lettuce cultivars tolerant to high temperatures. However, there is still a lack of information about their performance under high temperature conditions. This makes it difficult to recommend and produce good quality lettuce in different regions of the country (Sala and Costa, 2012).

As well as the cultivar, there are several cultural practices that comprise an improvement to the environment and affect the production of lettuce. Important among these is spacing, which influences performance regardless of the weather conditions to which the crop is submitted. Therefore, defining the best spacing to be adopted by the producer is essential. This is because plants respond to spacing by changes in architecture, development, weight, quality and finally, production (Mondin, 1989).

Some of the studies which test combinations between cultivars and spacings are intended to identify the combination which would result in greater productivity, precocity, product quality and tolerance to bolting (Echer et al., 2001; Lima et al., 2004). It is known that an increase in plants per unit area tends to increase production. However, as high plant densities do not always result in products of high commercial value, there is a limit to this increase (Correa et al., 2014). In very dense crops, there is greater competition among plants for light, water and nutrients, in which productivity tends to decrease. The aim of this study therefore, was to evaluate the productive and physiological performance of lettuce cultivars at different planting densities under semi-arid conditions.

MATERIALS AND METHODS

The experiment was carried out from August to October 2014 at the teaching garden of the Department for Phytotechnology of the Federal University of Ceará (UFC), on the Pici Campus in Fortaleza (3°36' S, 37°48' W, at an altitude of 21.0 m) in the State of Ceará, Brazil (CE). The climate, according to the Köppen classification, is of type Aw', that is, rainy tropical, with an average annual rainfall of 1,338 mm and minimum, maximum and average temperatures of respectively 23, 31 and 27°C.

The experimental design was of randomised blocks, with treatments arranged in a 4 × 4 factorial scheme, with four replications. The first factor comprised four cultivars (Red Salad Bowl, Salad Bowl Green, Crespa Lollo Bionda and Mimosa Green Salad Bowl) and the second comprised four spacings, 0.20 × 0.20 m (250,000 plants ha^{-1}), 0.25 × 0.25 m (160,000 plants ha^{-1}), 0.20 × 0.25 m (200,000 plants ha^{-1}) and 0.25 × 0.30 m (133,333 plants ha^{-1}), between plants and rows. One lot consisted of 16 plants, with the nine central plants used as the working area.

The cultivars used in the experiment 'Red Salad Bowl', 'Salad Bowl Green', 'Mimosa Green Salad Bowl' and 'Crespa Lollo Bionda', all of the 'Crisp Loose-leaf ' group, are very consistent, have leaves which are more separate (loose) with irregular leaf blades (crisp), and do not form a head. During the experiment, climate data relating to minimum and maximum temperature and rainfall were recorded (Figure 1).

The soil at the cultivation site is of a sandy-clay type, with a sandy-loam to clayey-loam texture. The production beds were constructed by hand with the aid of hoes, to have a soft-wavy relief. They were prepared with a length and width of 16 × 1 m, and a height of 0.2 m. Once built, the beds were fertilized with organic compost (a result of composting cattle manure and vegetable waste) and left for 15 days in order to improve the chemical and physical properties of the soil, a sample of which was then taken. The chemical analysis of the soil was based on Ribeiro et al. (1999) and gave the following result: pH (H_2O) = 6.62; P = 474.78 mg dm^{-3}; K^+ = 773.3 mg dm^{-3}; Na^+ = 146.35 mg dm^{-3}; Ca^{2+} = 6.11 cmolc dm^{-3}; Mg^{2+} = 4.19 cmolc dm^{-3}; (H+Al) = 1.43 cmolc dm^{-3}; BS = 12.92 cmolc dm^{-3}; T = 12.92 cmolc dm^{-3}; CEC = 14.34 cmolc dm^{-3}; V = 90% and PST = 4.5% .

Fertilisation at planting was based on the chemical analysis of the soil, and the fifth estimation handbook for the lettuce crop (Ribeiro et al., 1999), when the following were applied: 80 kg ha^{-1} urea (45% N); 1,344 kg ha^{-1} superphosphate (18.9% P_2O_5); 38 kg ha^{-1} potassium chloride (62% K_2O) and 12 kg ha^{-1} of micronutrient mixture (Agamix).

Lettuce seedlings were grown in polyethylene trays of 200 cells, with two seeds per cell. These were filled with organic compost (cattle manure and vegetables) and vermiculite at a ratio of 9:1 (v.v.). After sowing, the trays were placed in a greenhouse, which was covered in a white polyethylene diffuser film 150 µm thick, with a black shade screen retaining 30% of solar radiation flux. Irrigation was twice-daily by micro-sprinkler, once in the morning and once in the afternoon, in order to maintain the water content of the substrate close to field capacity.

At 14 days after sowing (DAS), the plants were thinned with the help of scissors, properly sanitised with 2% sodium hypochlorite, to leave only one seedling per cell. At 26 DAS, foliar fertilisation based on micronutrients was carried out using single mineral fertilizer (Nutr-I-Kelp), followed at 28 DAS by another foliar fertilisation with nitrogen (urea).

At 35 DAS, when the plants presented from four to six true leaves, they were transplanted to the beds at the pre-set densities, where holes had been marked out using a tape measure according to each spacing, and one seedling placed in each hole. This was done in the late afternoon (after 1600). Two applications of topdressing were made in the open, the first at 10 days after transplanting (DAT), when 80 kg ha^{-1} urea, 576 kg ha^{-1} superphosphate and 38 kg ha^{-1} potassium chloride were applied. The second was carried out at 20 DAT, applying 120 kg ha^{-1} urea

*Corresponding author. E-mail: hozanoneto@hotmail.com.

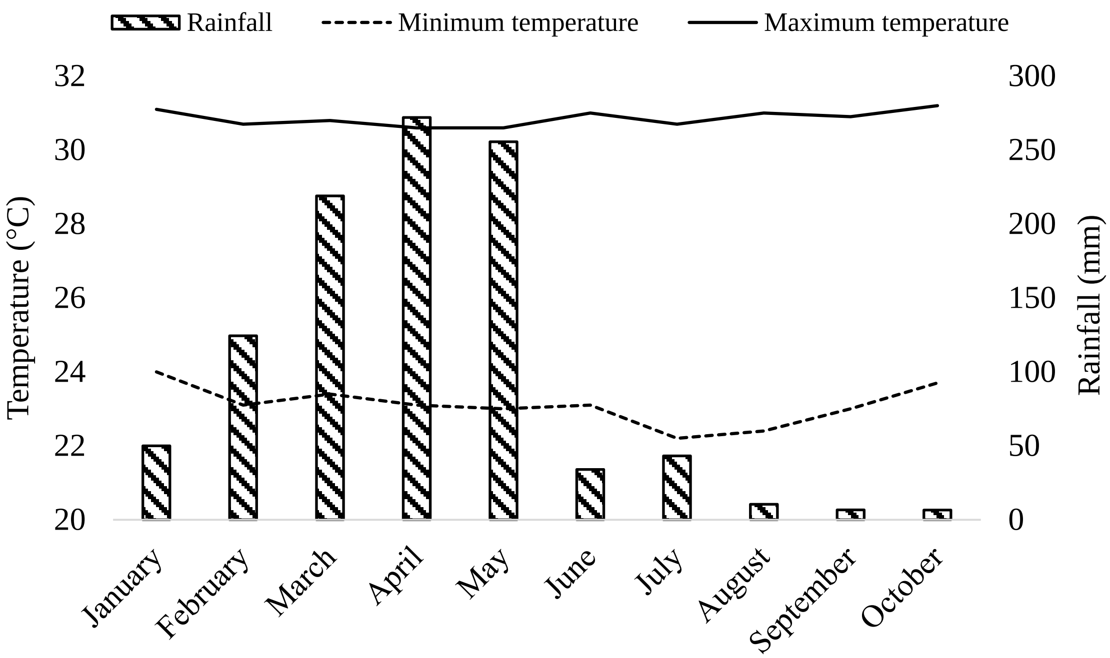

Figure 1. Temperature Analysis, maximum and minimum, and monthly rainfall in the municipality of Fortaleza-CE in 2014.

and 54 kg ha^{-1} potassium chloride. All topdressings were given based on the chemical analysis of the soil, as well as the fifth estimation for the lettuce crop (Ribeiro et al., 1999).

Weeding was by hand, with the weeds removed directly from the beds; pests and diseases were monitored throughout the experiment. No method of pest control was used as no infestation was found. For irrigation, a micro-sprinkler system was employed, with sprinklers having a working pressure, range, flow, head and size of 1.5-3.0 kg, 0.9-1.1 m, 33-55 L h^{-1}, 360° and 13 × 22 mm, respectively. The system was activated twice a day (early morning and late afternoon) in order to maintain the soil moisture close to field capacity. The irrigation depth was determined based on the water requirement of the crop, taking into account the crop coefficient for lettuce.

After 64 DAS, a physiological assessment was made on the third pair of fully expanded leaves, using an infrared gas analyser (IRGA), model LCi from ADC (Analytical Development Co. Ltd, Hoddesdon, UK). The CO_2 concentration of the sub-stomatal chamber (Ci - ppm) was determined, together with the stomatal conductance (*gs* - mol m^{-2} s^{-1}), the rate of photosynthesis (*A* - µmol m^{-2} s^{-1}), the ratio between the CO_2 concentration of the substomatal chamber and the CO_2 concentration of the environment (Ci/Ca), and the instantaneous carboxylation efficiency (*A*/Ci). The evaluations were made between 0800 and 1100, when the stomata were fully open, on a clear day, using artificial lighting of 1,000 µmol m^{-2} s^{-1} in the evaluation chamber of the equipment, in order to maintain more homogeneous environmental conditions during the evaluations.

Shortly after, a qualitative evaluation was made of the age at bolting (AB), considering the number of days from sowing until at least one of the plants from each cultivar displayed evidence of changing from the vegetative to the reproductive phase, which consisted of stem elongation with obvious spacing between leaves; the state of health of the plants (diseases), evaluated from the damage caused by the disease, and based on a visual rating scale ranging from 1 to 5, where: 1 for plants with leaves strongly attacked by disease; 3 for plants with leaves moderately attacked by disease; 4 for plants with leaves rarely attacked by disease and 5 for plants with leaves with no apparent attack by disease (Mota et al., 2003); the state of health of the plants (pests), as attacked by pests and based on a visual rating scale by Mota et al. (2003); and the age at flowering (AF), considering the number of days from sowing to the point of 'silking', which consists of not only stem elongation, but also the beginning of the formation of floral structures (Kristkova et al., 2008). To evaluate the AF, six other plants were grown in the same area from each cultivar, at each of the determined spacings and in each block.

At 65 DAS, the plants were harvested for quantitative assessment of plant height (AP), measured from the ground level to the end of the stem at the insertion point of the last developing leaf, using a graduated ruler and expressed in cm; plant diameter (PD), measured as the greatest distance between the tips of the opposing edges of the leaves, expressed in cm; commercial fresh weight (CFW), the weight of the commercial part of the crop when harvested in the morning (0900), expressed in g plant^{-1}; non-commercial fresh weight (NCFW), the weight of the non-commercial part of the crop, harvested in the morning (0900), expressed in g plant^{-1}; total fresh weight (TFW), the sum of the CFW and NCFW; and commercial dry weight (CDW) and non-commercial dry weight (NCDW), the weight of the commercial and non-commercial parts after drying in a forced air oven (65°C for 48 h) to constant weight, expressed in g plant^{-1}; and total dry weight (TDW), as the sum of the CDW and NCDW.

The results were submitted for analysis of variance (ANOVA) by F-test. Where there was a significant effect, the mean values were compared by Scott-Knott test at 5% significance.

RESULTS AND DISCUSSION

Morphological differences were found between the

Table 1. Morphological aspects in lettuce cultivars for spacing (Fortaleza CE, UFC, 2014).

Cultivar	AB (DAS)[1]	SPHD[3]	SPHP[4]	AF (DAS)[5]
Red Salad Bowl	61	5	5	80
Salad Bowl Green	63	5	5	95
Mimosa Green Salad Bowl	63	5	5	95
Crespa Lollo Bionda	61	5	5	72

AB, Age at bolting (DAS[1]): <50 DAS (early); 50-70 DAS (medium); >70 (late); SPHD, State of plant health (disease)[3]; SPHP, State of plant health (pests)[4]; AF, Age at flowering (DAS)[5]: <60 DAS (early); 60-80 DAS (medium); >80 (late).

lettuce cultivars (Table 1). Regardless of the spacing used, the four cultivars displayed average tolerance to bolting (61 and 63 DAS), according to the classification proposed by Kristikova et al. (2008). However, ‘Salad Bowl Green’ and ‘Mimosa Green Salad Bowl’ proved to be slightly more tolerant to bolting, taking up to two extra days to start the process. When it comes to lettuce produced under the climatic conditions found at low altitudes and low latitudes, the longer the plants remain in the field with no evidence of bolting, and the consequent reduction in quality, the greater the accumulation of photoassimilates in the shoots, with a resultant increase in leaf area. Therefore, the longer period spent in the field by the plants of these cultivars may have favoured their growth, making them more productive.

The high temperatures recorded during the experiment, with a minimum of 23°C and a maximum of 30°C (Table 1), negatively influenced the productive behaviour of the lettuce cultivars. Under such conditions, there is a reduction in the vegetative stage and the harvest is brought forward. When this happens, the crop accumulates both quantitative and qualitative losses. Quantitatively, losses are caused mainly due to stem elongation and the consequent lower ‘investment’ in the production of leaves per plant. Qualitatively, the high temperatures induce early flowering, which is accompanied by latex production in the plant, making the leaves bitter and unpleasant (Vargas et al., 2014).

As to diseases and pests, none of the cultivars displayed apparent spots or any type of injury from insect predation, and were therefore considered healthy (Table 1). According to Sala and Costa (2012), lettuces classified as crisp have better resistance to disease, pests and transportation, and a greater post-harvest period when compared to other commercial groups of the same crop. This resistance is mainly related to the arrangement of the leaves on the plant. Because they are more upright and the plant architecture is more open, water does not accumulate during the hot, rainy summer, resulting in fewer losses due to rotting of the leaves and attack by pathogens.

‘Red Salad Bowl’ and ‘Crespa Lollo Bionda’ displayed average tolerance for AF, flowering at 80 and 72 DAS respectively. Whereas, ‘Salad Bowl Green’ and ‘Mimosa Green Salad Bowl’, flowering at 95 DAS, were classified as late for AF (Kristkova et al., 2008).

The combination of long days (more than 10 h light) and high temperatures (an average of approximately 27°C) had an influence on bolting and emission of the floral tassel. However, according to Vargas et al. (2014), flowering in the lettuce may be influenced by not only temperature and length of day, but also the genetic load of the cultivars. That statement can be confirmed in this work, since the cultivars presented different ages at bolting and flowering, despite being subjected to the same conditions of soil and climate.

There was interaction between cultivar and spacing ($p<0.01$) for all the quantitative characteristics under study, demonstrating that the cultivars respond differently as the spacing is changed. ‘Red Salad Bowl’ had the highest average plant height (Table 2). At the spacing of 0.25 × 0.25 m, the plants reached on average the greatest height for each cultivar.

Under conditions of high temperature and luminosity, such as those that occur in the climate of regions of low altitude and low latitude, greater plant height is related to early bolting (Santos et al., 2009). This claim was partially confirmed in this work, as ‘Red Salad Bowl’, one of the first to show signs of bolting, at 61 DAS, also had the highest average height among all the cultivars being evaluated. This different behaviour between cultivars is related to their gene load. The larger values for height may be related to early flowering. This is because, due to the heat, early bolting causes stem elongation and hampers the formation of a commercial head. The result is the plant being harvested while still small and of poor quality, not expressing all its productive genetic potential (Vargas et al., 2014).

‘Salad Bowl Green’ was the cultivar with the greatest average diameter. As for the spacings under evaluation, it should be noted that at 0.20 × 0.20 m the cultivars presented plants with an average diameter of 20.6 cm (Table 2).

The results of this study are similar to those seen by Batista et al. (2007), who worked with the Itapuã, Elba and Veneranda cultivars and found that plant diameter ranged from 20.4 to 23.5 cm. Rodrigues et al. (2008) also worked under conditions of high temperature in Manaus in the State of Amazonas, and observed a plant diameter of 13.6 cm in ‘Crespa Lollo Bionda’, similar to that found

Table 2. Height and diameter in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

			Plant height (cm)		
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	6.37^{aA}	5.89^{aB}	4.66^{bD}	5.54^{aC}	5.61^{a}
Salad bowl green	5.75^{bA}	5.91^{aA}	5.15^{aB}	5.09^{bB}	5.47^{b}
Mimosa green salad bowl	4.71^{cB}	5.90^{aA}	4.46^{bB}	3.97^{cC}	4.76^{c}
Crespa Lollo Bionda	3.75^{dA}	3.81^{bA}	3.50^{cA}	3.73^{cA}	3.69^{d}
Mean	5.14^{B}	5.37^{A}	4.44^{D}	4.58^{C}	
C.V. (%)	3.55				
			Plant diameter (cm)		
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	18.28^{bA}	16.97^{bA}	16.55^{cA}	16.81^{cA}	17.15^{c}
Salad bowl green	24.72^{aA}	24.51^{aA}	25.83^{aA}	25.83^{aA}	25.22^{a}
Mimosa green salad bowl	25.72^{aA}	24.14^{aA}	22.59^{bA}	21.27^{bA}	23.42^{b}
Crespa Lollo Bionda	13.87^{cA}	14.35^{cA}	13.91^{dA}	14.12^{dA}	14.06^{d}
Mean	20.64^{A}	19.99^{B}	19.71^{B}	19.50^{B}	
CV (%)	5.74				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

Table 3. Commercial fresh weight (CFW), non-commercial fresh weight (NCFW), total fresh weight (TFW) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

			Commercial fresh weight (g plant^{-1})		
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	14.01^{cA}	11.45^{cB}	9.47^{cB}	10.99^{cB}	11.47^{c}
Salad bowl green	46.04^{aD}	57.47^{aB}	53.33^{aC}	71.64^{aA}	57.14^{a}
Mimosa green salad bowl	28.37^{bC}	50.75^{bA}	37.15^{bB}	30.09^{bC}	36.59^{b}
Crespa Lollo Bionda	8.99^{dB}	11.00^{cB}	8.93^{cB}	13.47^{cA}	10.60^{c}
Mean	24.35^{C}	32.66^{A}	27.24^{B}	31.54^{A}	
CV (%)	6.11				
			Non-commercial fresh weight (g plant^{-1})		
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Me^{a}n
Red salad bowl	4.33^{dA}	3.27^{dB}	3.64^{cB}	3.41^{cB}	3.66^{d}
Salad bowl green	12.81^{aB}	17.57^{aA}	12.57^{aB}	13.44^{aB}	14.09^{a}
Mimosa green salad bowl	7.63^{bB}	11.36^{bA}	10.74^{bA}	6.03^{bC}	8.93^{b}
Crespa Lollo Bionda	6.25^{cB}	5.49^{cB}	4.18^{cA}	6.03^{bB}	5.49^{c}
Mean	7.75^{B}	9.42^{A}	7.78^{B}	7.22^{C}	
CV (%)	7.25				
			Total fresh weight (g plant^{-1})		
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Me^{a}n
Red salad bowl	18.34^{cA}	14.72^{cB}	13.11^{cB}	14.39^{dB}	15.14^{c}
Salad bowl green	58.85^{aD}	75.04^{aB}	66.01^{aC}	85.09^{aA}	71.24^{a}
Mimosa green salad bowl	35.99^{bC}	62.11^{bA}	47.89^{bB}	36.13^{bC}	45.53^{b}
Crespa Lollo Bionda	15.24^{dB}	16.50^{cB}	13.11^{cB}	19.51^{cA}	16.09^{c}
Mean	32.10^{D}	42.09^{A}	35.03^{C}	38.77^{B}	
CV (%)	5.22				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

in the present work for the same cultivar (14.06 cm). This similarity between results may be related to climate conditions at the two study sites. As for CFW, NCFW and TFW (Table 3), 'Salad Bowl Green' stands out with higher averages than the other cultivars. Among the spacings, at 0.25 × 0.25 m and 0.25 × 0.30 m the plants had, on average, the highest values for CFW, of 32.66 and 31.54 g plant^{-1} respectively. Yet, at the spacing of 0.25 × 0.25 m, the plants also achieved the greatest average values for NCFW and TFW.

The largest spacings between plants, 0.25 × 0.25 m and 0.25 × 0.30 m, contributed to the greatest increments in CFW, this because when plants are more widely spaced, there is a smaller overlap between the leaves, resulting in leaves which are larger and of better commercial quality. Santos et al. (2009), working with cultivars of crisp lettuce at a spacing of 0.25 × 0.30 m under high temperature conditions, in Cáceres in the State of Mato Groso, found values for CFW that ranged from 29.0 to 104.3 g plant^{-1}. Similarly, Rodrigues et al. (2008) evaluated different lettuce cultivars of the same group in Iranduba, Amazonas, which has similar mean temperatures to Fortaleza, CE. Those researchers found average values for CFW that varied from 25.5 to 96.7 g plant^{-1}.

With the Salad Bowl Green cultivar, it became clear that the largest spacings between plants afforded the greatest individual average values for production per plant. At the spacing of 0.25 × 0.30 m (133,333 plants ha^{-1}) for example, the average weight per plant was 85.09 g, compared to 75.04 g at the spacing of 0.25 × 0.25 m (160,000 plants ha^{-1}), 66.01 g at 0.20 × 0.25 m (200,000 plants ha^{-1}) and 58.85 g at 0.20 × 0.20 m (250,000 plants ha^{-1}).

This result may be related to less shading being produced between neighbouring plants at the larger spacings. Less shading allows more light to be intercepted by the plants, giving greater efficiency in carrying out photosynthesis, and consequently a greater production of photoassimilates that will contribute to the accumulation of mass and the production of plant tissue (Larcher, 2004). This hypothesis may be strengthened by observing the results of net photosynthesis on these treatments, where plants of this cultivar, when grown at the spacing of 0.25 × 0.30 m, had the greatest rates for net photosynthesis, with a lower mean value seen at the spacing of 0.20 × 0.20 m. For Mondim (1989), larger spacings tend to give an increase in shoot fresh weight, mainly due to less competition between plants for light, water and nutrients.

Rodrigues et al. (2008) in Iranduba, Amazonas, and Santos et al. (2009) in Cáceres, Mato Grosso, worked with different cultivars of crisp lettuce, and found average values for TFW of 29.33 to 104.61 g plant^{-1} and 52.50 to 111.50 g plant^{-1} respectively. Lima et al. (2004) worked with the Vera and Verônica cultivars at two spacings (0.20 × 0.20 m and 0.20 × 0.30 m), in Ribeirão Preto in Sâo Paulo, at maximum and minimum temperatures close to those seen during this study (31 and 20°C respectively). Those authors found that a spacing of 0.20 × 0.30 m, gave higher average values for TFW per plant in the Veronica cultivar.

Plants grown at larger spacings produced, on average, higher individual values for CFW and TFW. However, the smaller spacings were responsible for the largest average values for productivity, due to the larger number of plants per area. Echer et al. (2001) also found higher average values for production at a spacing of 0.20 × 0.20 m when growing lettuce, which may be related to the fact that as the spacing decreases and the population density increases within certain limits, there is a tendency for the total production per area to increase, which can result in greater profitability to the producer.

Similar responses were observed with the fresh and dry commercial, non-commercial and total weights (Table 4). Following the same trend, the Salad Bowl Green cultivar had average values higher than the other cultivars. Among the spacings, 0.25 × 0.25 m and 0.25 × 0.30 m should be noted, as they gave, on average, the greatest values for CDW. However, the former spacing also gave the largest values for NCDW and TDW.

Batista et al. (2007), working in Iguatu, CE, with the Itapuã, Elba and Veneranda cultivars, at a spacing of 0.25 × 0.25 m, found that CDW ranged from 12.7 to 15.3 g plant^{-1}. This variation was much higher than seen in the present work. This difference may be related to when the work was carried out. Although Iguatu has similar climatic conditions to Fortaleza, the experiment conducted by those authors was during the rainy season, when levels of radiation and temperature tend to be milder, favouring the development of the lettuce plants.

For the characteristics of gas exchange, the Red Salad Bowl cultivar displayed the highest internal CO_2 concentrations (Ci) and Ci/Ca ratio (Table 5). On the other hand, ‘Salad Bowl Green’, which had the highest average values for TFW and TDW, also displayed the lowest values for Ci and Ci/Ca, together with ‘Mimosa Green Salad Bowl’. For spacing, the plants presented the highest average concentrations of Ci and Ci/Ca at the spacing of 0.20 × 0.20 m.

For instantaneous carboxylation efficiency (*A*/Ci), the Mimosa Green Salad Bowl and Salad Bowl Green cultivars displayed the highest average values, not differing from each other, but differing from the other cultivars. The spacing of 0.20 × 0.25 m gave the best average value for carboxylation efficiency between the cultivars.

In general, a joint interpretation is necessary to better understand the physiological characteristics. However, as this is a complex discussion, it was performed using only the most relevant search results, that is, the cultivar (Salad Bowl Green) that had the highest values for fresh and dry weight, and the spacing (0.20 × 0.20 m) which gave the greatest values for productivity by weight per hectare. 'Salad Bowl Green' had one of the lowest average values for Ci (Table 5). On the other hand, it had one of the higher average values for rate of photosynthesis (*A*). The higher the value of *A*, the faster

Table 4. Commercial dry weight (CDW), non-commercial dry weight (NCDW) and total dry weight (TDW) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Commercial dry weight (g plant^{-1})					
Cultivar	**0.20 × 0.20**	**0.25 × 0.25**	**0.20 × 0.25**	**0.25 × 0.30**	**Mean**
Red salad bowl	0.89^{cA}	0.72^{cB}	0.59^{cB}	0.82^{cA}	0.75^{c}
Salad bowl green	2.47^{aD}	3.31^{aB}	3.03^{aC}	4.06^{aA}	3.21^{a}
Mimosa green salad bowl	1.79^{bC}	2.59^{bA}	2.15^{bB}	1.44^{bD}	1.99^{b}
Crespa Lollo Bionda	0.54^{dB}	0.75^{cA}	0.55^{cB}	0.80^{cA}	0.66^{d}
Mean	1.42^{C}	1.84^{A}	1.58^{B}	1.78^{A}	
CV (%)	5.64				
Non-commercial dry weight (g plant^{-1})					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Me^{a}n
Red salad bowl	0.37^{cA}	0.28^{dB}	0.29^{dB}	0.30^{dB}	0.31^{d}
Salad bowl green	0.69^{aC}	0.89^{aA}	0.78^{aB}	0.90^{aA}	0.81^{a}
Mimosa green salad bowl	0.49^{bA}	0.65^{bA}	0.65^{bA}	0.52^{bC}	0.54^{b}
Crespa Lollo Bionda	0.39^{cB}	0.42^{cB}	0.33^{cC}	0.37^{cA}	0.41^{c}
Mean	0.48^{C}	0.56^{A}	0.51^{B}	0.52^{B}	
CV (%)	4.51				
Total dry weight (g plant^{-1})					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	1.27^{cA}	1.00^{dB}	0.88^{cB}	1.12^{dA}	1.07^{c}
Salad bowl green	3.15^{aD}	4.20^{aB}	3.18^{aC}	4.96^{aA}	4.03^{a}
Mimosa green salad bowl	2.29^{bC}	3.24^{bA}	2.80^{bB}	1.81^{bD}	2.53^{b}
Crespa Lollo Bionda	0.93^{dA}	1.17^{cB}	0.88^{cB}	1.32^{cA}	1.07^{c}
Mean	1.91^{D}	2.41^{A}	2.09^{C}	2.30^{B}	
CV (%)	4.95				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

Table 5. Average values for internal CO_2 concentration (Ci), the Ci/Ca ratio and instantaneous carboxylation efficiency (*A*/Ci) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Internal CO_2 concentration (ppm)					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	316.94^{aA}	304.69^{aB}	290.81^{bC}	311.75^{aA}	306.04^{a}
Salad bowl green	298.94^{bA}	283.56^{bC}	289.50^{bB}	273.94^{dD}	286.48^{c}
Mimosa green salad bowl	291.25^{bA}	269.69^{cC}	281.19^{cB}	292.19^{bA}	283.57^{c}
Crespa Lollo Bionda	316.25^{aA}	287.56^{bC}	299.13^{aB}	284.06^{cC}	296.75^{b}
Mean	305.84^{A}	286.37^{B}	290.15^{B}	290.48^{B}	
CV (%)	1.88				
Ci/Ca ratio					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	0.86^{aA}	0.82^{aB}	0.78^{aC}	0.84^{aA}	0.82^{a}
Salad bowl green	0.81^{bA}	0.76^{cC}	0.78^{aB}	0.73^{dC}	0.77^{c}
Mimosa green salad bowl	0.78^{bA}	0.73^{dC}	0.75^{bB}	0.78^{bA}	0.76^{c}
Crespa Lollo Bionda	0.85^{aA}	0.79^{bB}	0.79^{aB}	0.76^{cC}	0.80^{b}
Mean	0.82^{A}	0.77^{B}	0.77^{B}	0.78^{B}	
CV (%)	1.96				
Instantaneous carboxylation efficiency					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	0.04^{cD}	0.04^{dC}	0.05^{cA}	0.05^{cB}	0.052^{c}
Salad bowl green	0.05^{bC}	0.05^{bB}	0.06^{bB}	0.06^{aA}	0.060^{a}

Table 5. Contd.

Mimosa green salad bowl	0.06^{aB}	0.06^{aA}	0.07^{aA}	0.05^{cC}	0.061^{a}
Crespa Lollobionda	0.04^{bD}	0.05^{cC}	0.06^{bB}	0.06^{bA}	0.057^{b}
Mean	0.051^{D}	0.057^{C}	0.061^{A}	0.060^{B}	
CV (%)	2.55				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

Table 6. Mean values for stomatal conductance (*gs*) and photosynthesis (*A*) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Stomatal conductance (mol m^{-2} s^{-1})					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	0.28^{cC}	0.29^{cC}	0.36^{bB}	0.44^{aA}	0.34^{d}
Salad bowl green	0.32^{cC}	0.59^{aA}	0.47^{aB}	0.36^{bC}	0.43^{b}
Mimosa green salad bowl	0.40^{bB}	0.32^{cC}	0.50^{aA}	0.28^{cC}	0.37^{c}
Crespa Lollo Bionda	0.57^{aA}	0.43^{bC}	0.51^{aB}	0.39^{bD}	0.47^{a}
Mean	0.39^{B}	0.41^{B}	0.46^{A}	0.36^{C}	
CV (%)	7.37				
Photosynthesis (μmol m^{-2} s^{-1})					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	14.65^{cB}	14.89^{dB}	16.79^{bA}	16.79^{bA}	15.78^{b}
Salad bowl green	15.81^{bC}	16.65^{bB}	16.88^{bB}	18.20^{aA}	16.88^{a}
Mimosa green salad bowl	16.93^{aB}	17.56^{aA}	17.84^{aA}	16.15^{bC}	17.12^{a}
Crespa Lollo Bionda	15.61^{bB}	16.01^{cB}	17.87^{aA}	18.09^{aA}	16.89^{a}
Mean	15.75^{C}	16.27^{B}	17.34^{A}	17.30^{A}	
CV (%)	3.12				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

the internal CO_2 is consumed, that is, the greater the carboxylation efficiency (*A*/Ci). With the reduction in internal CO_2, the plant stimulates opening of the stomata, favouring an increase in the value for stomatal conductance. The cultivar in question displayed one of the highest values for *A*/Ci and stomatal conductance (gs), with the latter indicating a greater stomatal opening than the other cultivars (Tables 5 and 6). When the internal CO_2 is consumed quickly, mainly due to the higher rates of photosynthesis, the Ci/Ca ratio, which estimates the relationship between the internal and external concentration of CO_2 in the leaf, tends to be lower. When this happens, the efficiency of the photosynthesis will be greater, which may have a positive effect on production (Kaschuk et al., 2012), as verified in 'Salad Bowl Green', with one of the lowest values for the Ci/Ca ratio.

The average results for the spacings under evaluation can also be interpreted in the same way. The smallest spacing (0.20 × 0.20 m) made it possible to obtain plants with a greater value for Ci (Table 5). In turn, higher values for Ci may be related to the shading caused by the plants to each other due to the high planting density. This can be confirmed by two other physiological characteristics, *A* and *A*/Ci. Moreover, the spacing may have resulted in a lower vapour pressure deficit (VPD) that justified this behaviour, especially of the stomata.

The said spacing resulted in the lowest average values for weight in the cultivars under study. With the reduced use of internal CO_2, plants subjected to this spacing end up having to open their stomata at a lower intensity, this reduces stomatal conductance and consequently the Ci/Ca ratio, which is influenced more by the internal concentration of CO_2 in the plant than by that of the atmosphere, which under normal conditions tends to be stable.

The Crespa Lollo Bionda cultivar had the highest average value for stomatal conductance (*gs*) (Table 6), while the spacing of 0.20 × 0.25 m gave the highest average value of *gs* for the cultivars.

Stomatal conductance is an important parameter in predicting water use and net photosynthesis, being controlled by the turgidity of the guard cells that regulate the opening or closing of the stomata. Luminous intensity, relative humidity and wind intensity, among others, are some of the main factors responsible for this process (Taiz and Zeiger, 2013).

It is important to point out that the densest spacings (0.20 × 0.20 m, 0.20 × 0.25 m and 0.25 × 0.25 m) generally displayed higher values for *gs*, indicating a wider opening of the stomatal pores. This may have been due to the existence of the factor known as decoupling, where the higher plant density causes a reduction in the speed of the atmospheric air currents, this reduces the effect of air exchange by the winds in the atmospheric stratum in which the shoots of the lettuce plants are inserted (Larcher, 2004; Taiz and Zeiger, 2013).

In addition to this effect, the wind also acts by removing the boundary layer of air. This layer, in turn, aids in reducing transpiration, as it acts as a barrier to the air both leaving and entering the stoma, which favours the stomatal pore remaining open. The denser the plants, the greater the protection one plant affords another against the wind, that is, if the air layer internal to the aerial part of the plant is moving slowly, the decoupling factor is high, and the stomata tend to remain open to a greater degree and for a longer period, which increases the *gs* when the measurement is taken. Whereas in crops where the spacings are larger, the plants tend to be influenced more by the winds. In this case, the decoupling factor is low or may be nil. Also the boundary layer of air that would enable a reduction in water loss by the stomata, keeping them open for longer and to a greater degree, once removed, causes a reduction in the level of stomatal opening, resulting in a decrease in *gs* (Larcher, 2004; Taiz and Zeiger, 2013). This plant mechanism can be considered as a defence, since it avoids an excessive loss of water through the stomatal pores.

The Salad Bowl Green, Green Mimosa Salad Bowl and Crespa Lollo Bionda cultivars displayed the highest rates of photosynthesis, as did the spacings of 0.20 × 0.25 m and 0.25 x 0.30 m.

The physiological results seen in the plants of all the cultivars when grown at a spacing of 0.20 × 0.20 m, include the lowest average value for fresh and dry weight achieved by the plants. However, as noted above, this result was offset by the greater quantity of plants produced per area, which, although they were smaller, resulted in greater productivity.

Conclusion

The Salad Bowl Green and Green Mimosa Salad Bowl cultivars displayed the best productive and physiological performance when grown at smaller spacings and under semi-arid conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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