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Production and postharvest quality of jambu in hydroponics under nitrogen application in nutrient solution[1]

Produção e qualidade pós-colheita do jambu em hidroponia sob concentrações de nitrogênio na solução nutritiva

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ABSTRACT - Jambu is a leafy vegetable from the northern region of Brazil and its cultivation in the soil has considerably reduced its production, due to pests and diseases. Based on this, the objective of this work was to evaluate the growth, yield and postharvest quality of hydroponic jambu plants in response to the variation of nitrogen (N) concentration in the nutrient solution. The design used was completely randomized with eight replicates and six treatments, consisting of N concentrations in the nutrient solution (11, 13, 15, 17, 19 and 21 mmol L^{-1}). Main stem length (MSL), diameter (D), leaf area (LA), number of inflorescences (NI), shoot fresh mass (SFM), shoot dry mass (SDM), root fresh mass (RFM), root dry mass (RDM), inflorescence fresh mass (IFM), inflorescence dry mass (IDM), N content, total soluble solids (TSS), pH, titratable acidity (TA) and TSS/TA ratio were evaluated. Both growth and yield were explained by positive linear models, and the best results were obtained at the N concentration of 21 mmol L^{-1}. As for the quality variables TSS and TSS/TA, these were also explained by increasing linear models with maximum responses at the N concentration of 21 mmol L^{-1}. As the N concentration increased, there were reductions in TA. Based on the results, the N concentration of 21 mmol L^{-1} in the nutrient solution enables better response in terms of growth, production and postharvest quality in jambu.

Key words: Soilless cultivation. *Acmella oleracea* (L.). Titratable acidity. Brix

RESUMO - O jambu é uma hortaliça folhosa da região norte brasileira e seu cultivo no solo têm reduzido consideravelmente a sua produção, devido as pragas e doenças. Com base nisso, o objetivo deste trabalho foi avaliar o crescimento, a produção e a qualidade pós-colheita de plantas de jambu cultivadas em hidroponia em resposta a variação da concentração de nitrogênio na solução nutritiva. O delineamento utilizado foi inteiramente casualizado com oito repetições e seis tratamentos constituídos por concentrações de nitrogênio na solução nutritiva (11, 13, 15, 17, 19 e 21 mmol L^{-1} de N). Avaliou-se o comprimento da haste principal (CHP), diâmetro (D), área foliar (AF), número de inflorescências (NI), massa fresca da parte aérea (MFPA), massa seca da parte aérea (MSPA), massa fresca da raiz (MFR), massa seca da raiz (MSR), massa fresca da inflorescência (MFI), massa seca da inflorescência (MSI), concentração de N, sólidos solúveis totais (SST), pH, acidez titulável (AT) e a relação SST/AT. Tanto o crescimento como a produção foram explicados por modelos lineares positivos, de modo que os melhores resultados foram obtidos na concentração de 21 mmol L^{-1} de N. Quanto às variáveis de qualidade SST e a relação SST/AT, estas foram, também, explicadas por modelos lineares crescente com máximas respostas na concentração de 21 mmol L^{-1} de N. À medida que se aumentou a concentração de nitrogênio houve reduções da AT. Com base nos resultados, a concentração de 21 mmol L^{-1} de N na solução nutritiva possibilita melhor resposta em termos de crescimento, produção e qualidade pós-colheita no jambu.

Palavras-chave: Cultivo sem solo. *Acmella oleracea* (L.). Acidez titulável. Brix.

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INTRODUCTION

Considered a species of the Amazon region, northern Brazil, jambu (*Acmella oleracea* (L.) R. K. Jansen) is a herbaceous leafy vegetable that has peculiar properties, such as the momentary anesthetic sensation caused by the consumption of its vegetative parts, mainly, of inflorescences (HOMMA, 2014). This sensation comes from the action of the bioactive compound spilanthol and this substance has been exploited by the industry due to its pharmacological properties, such as anti-inflammatory and anesthetic (BARBOSA *et al*., 2016). In addition, the crop has significant importance as a condiment of typical dishes of the northern region, for example tacacá, which is considered intangible cultural heritage of the city of Belém (SILVA *et al.*, 2020).

Jambu cultivation in soil is carried out by direct sowing in furrows in soil, a management that leads to low uniformity and quality of plants (SAMPAIO *et al*., 2019) and facilitates the occurrence of diseases of economic importance such as coal (*Thecaphora spilanthes* Frei. & Van.) and rust (*Puccinia sp.*), which cause significant losses (HOMMA, 2014). It is worth pointing out that, although the study conducted by Sampaio *et al*. (2018), improves the conventional production system of jambu, mainly due to the adoption of seedlings, this management does not guarantee the absence of losses caused by pests and diseases that occur in the cultivation in soil.

To reduce production losses in the soil cultivation of jambu, an alternative would be the use of hydroponic system. This cultivation system, which uses nutrient solution instead of soil, has advantages such as lower use of area and inputs, mainly water and fertilizers, absence of soil diseases, higher yield, as well as better quality of plants (SAMBO *et al*., 2019). However, little is known about the nutritional dynamics of this crop in this system, as well as its productive and qualitative behavior as a function of variations of nutrients in the nutrient solution.

In soil cultivation, in both conventional and organic systems, studies have demonstrated higher productivity and quality of jambu due to increased nitrogen (N) supply through N fertilization (BORGES *et al*., 2013; SOUTO *et al*., 2018), indicating the importance of this element in maintaining the production and quality of the crop. Thus, it is necessary to deepen the studies on N in nutrient solutions for the cultivation of jambu in hydroponic systems.

Research has shown the important role of N both in the increase of production and in the improvement of the postharvest quality of vegetables (CECÍLIO FILHO *et al*., 2017; MAHLANGU *et al*., 2016; MASHABELA *et al*., 2018; RODRIGUES *et al*., 2014). In Brazil, postharvest losses in vegetables reach on average 35 to 40%, being the largest source of financial loss for producers (HOQUE *et al*., 2010). These losses are mainly related to the physical aspect, since consumers evaluate the products mainly based on their appearance (CHITARRA; CHITARRA, 2005), which shows the importance of mineral nutrition in maintaining both production and qualitative parameters of vegetables.

Based on the above, the objective was to evaluate the growth, production and postharvest quality of jambu plants grown in hydroponics in response to the variation of N concentration in the nutrient solution.

MATERIAL AND METHODS

The experiment was conducted in a A-frame greenhouse with ridge vent, covered with 100 -µm low-density polyethylene (LDPE), with width of 8 m, length of 15 m and ceiling height of 3.5 m, and sides covered with 40 -mm galvanized wire screen, located in the area of Soil Science, of the Institute of Agrarian Sciences of the Federal Rural University of the Amazon, Belém campus, with the following coordinates: 1°40' S latitude and 48°42' W longitude. The climate is classified as Afi according to Köppen's classification (ALVARES *et al.*, 2013). During the experimental period, air temperature and relative humidity were monitored daily using a digital hygrometer installed inside the greenhouse. The average maximum air temperature was 35.8 °C and the minimum temperature was 28.1 °C. The average relative humidity was 77.1%.

The experimental design used was completely randomized with six treatments and eight replicates. The treatments consisted of N concentrations in the nutrient solution (11, 13, 15, 17, 19 and 21 mmol L^{-1} of N) using as reference the Hoagland and Arnon (1950) solution 2 formulation, where the standard N concentration of the formulation is equivalent to 15 mmol L^{-1} (Table 1).

The experiment was conducted using the yellow flower variety of jambu (*Acmella oleracea* (L.) R. K. Jansen) (GUSMÃO; GUSMÃO, 2013) obtained from the active germplasm bank in the garden area linked to the Institute of Agricultural Sciences (ICA) whose coordinates are 01°27'19" S and 48°26'20" W.

Sowing was performed in polystyrene trays of 128 cells filled with substrate based on coconut powder (Table 2). After emergence, the trays were transferred to wooden countertops. Every two days, the trays were irrigated with nutrient solution of Hoagland and Arnon (1950) with 25% of the nutrient concentration. At seven days after sowing, thinning was performed, leaving one seedling per cell. The experimental units consisted of plastic pots with capacity for 2 L and filled with ground silica (SiO_2) (substrate) containing one jambu seedling.

Table 1 – Stock solutions and quantity used in the solution (mL L^{-1}) to prepare the treatments. Belém, Pará, 2019

Stock Solution (1 M)	Treatments (mmol L^{-1})					
	11	13	15	17	19	21
$NH_4H_2PO_4$	1	1	1	1	1	1
KNO_3	2	4	6	6	6	6
$Ca(NO_3)_2$	4	4	4	4	5	4
$MgSO_4$	2	2	2	2	2	2
KCl	4	2	-	-	-	-
$NaNO^3$	-	-	-	-	2	4
NH_4NO_3	-	-	-	1	1	1
Micro[1]	1	1	1	1	1	1
Fe-EDTA[2]	1	1	1	1	1	1

[1]Stock Solution of Micronutrients: 2.86 g/L of H_3BO_3, 1.81 g/L of $MnCl_2.4H_2O$, 0.22 g/L of $ZnSO_4.5H_2O$, 0.08 g/L of $CuSO_4.5H_2O$, and 0.02 g/L of $H_2MoO_4.H_2O$. [2]Fe-EDTA: 21.6 g/L EDTA, 286 mL/L 1M KOH and 24.9 g/L $FeSO_4.7H_2O$

Table 2 - Chemical characterization of the coconut powder substrate used for the production of jambu (*Acmella oleracea*) seedlings. Belém, Pará, 2019

N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
ppm											
42	21	22	186	39	37	1	5	14	3	2	4

At 21 days after sowing, the seedlings were transplanted to the pots. After transplantation, jambu plants underwent a seven-day period of acclimatization to the hydroponic system, receiving nutrient solution at 50% of nutrient concentration (HOAGLAND; ARNON, 1950) and, after this period, were subjected to their respective treatments.

During the experiment, the nutrient solutions were oxygenated by draining the solution in the late afternoon and replacing it in the early morning, every day. The solutions were renewed weekly, when there is a 50% reduction in the concentration of nutrients. The pH values of the solutions were monitored daily by pocket pH meter and kept within the range from 5.5 to 6.5. When necessary, the pH was corrected using 1 N NaOH or 1 N citric acid ($C_6H_8O_7$). The water lost by evapotranspiration was daily replaced in order to maintain a volume of 400 mL per pot, using distilled water.

Harvest was performed 56 days after sowing, when the following characteristics were analyzed: a) main stem length (MSL) - determined using a graduated ruler (cm); b) diameter (D) - determined using a digital caliper (mm); c) leaf area - measured in cm² plant^{-1} using a leaf area integrator model LI-3100 (LI-COR, Lincoln, NE, USA); d) number of inflorescences (NI) - determined by simple count; e) shoot fresh mass (SFM) - measured in g plant^{-1}; (f) shoot dry mass (SDM) - determined in g plant^{-1}; g) root fresh mass (RFM) - determined in g plant^{-1}; h) root dry mass (RDM) - measured in g plant^{-1}; (i) inflorescence fresh mass (IFM) - determined in g plant^{-1}; and j) inflorescence dry mass (IDM) - measured in g plant^{-1}.

The fresh masses were determined after the separation of each part and weighing on a precision scale. To determine the dry mass, the samples of each part were placed in paper bags, dried in an oven at temperature of 65 ºC for 72 hours, and then weighed on a precision analytical scale. From this, leaf samples were crushed in a Wiley-type mill, passed through a 20-mesh sieve and stored to determine the total N content by the sulfuric digestion method (Kjeldahl), according to the methodology of Silva (2009).

In addition, the following postharvest variables were also analyzed:

a) Total soluble solids (TSS) **-** determined using a digital refractometer, with automatic temperature correction, after maceration of 1.0 g of leaves in a mortar and transferring of two to three drops to the device's prism (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTRY, 2012). The results were expressed in ºBrix (%);

b) Titratable acidity (TA) - determined using 1.0 g of leaf macerated with distilled water, with 1% phenolphthalein indicator and titration with 0.1 N NaOH solution (INSTITUTO ADOLFO LUTZ, 2008). The results were expressed in grams of oxalic acid per 100 g of leaf;

c) pH - determined after maceration of 1.0 g of leaf diluted in 30 mL of distilled water using a benchtop digital pH meter with glass membrane (INSTITUTO ADOLFO LUTZ, 2008);

d) TSS/TA ratio - determined by the direct relationship between the quotient of soluble solids and titratable acidity.

The data were subjected to analysis of variance by the F test at 5% probability level and, when significant, regression models were fitted for N concentrations in the nutrient solution. The analyses were performed using the statistical program Sisvar® (FERREIRA, 2011).

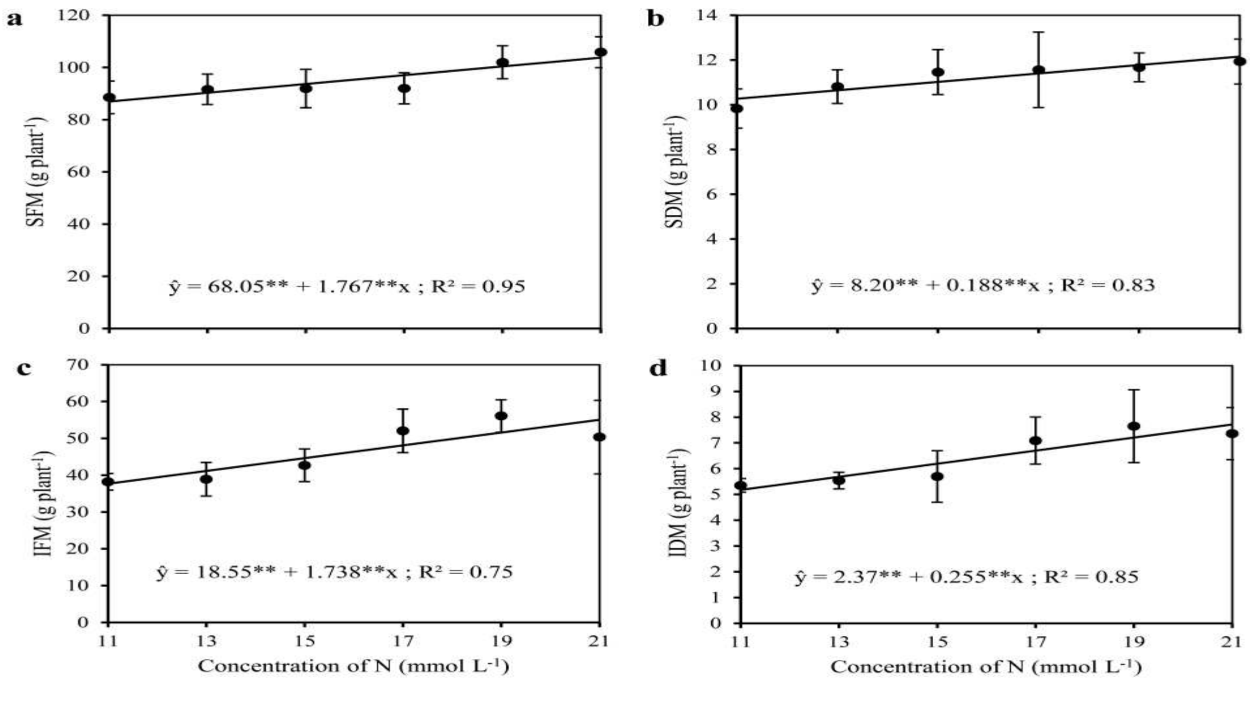
RESULT AND DISCUSSION

The increase in N concentration in the nutrient solution did not influence the variables MSL, D, RFM and RDM, with mean values of 24.19 cm, 6.49 mm, 20.81 g plant^{-1} and 1.89 g plant^{-1}, respectively. The absence of influence of N concentrations on the RFM and RDM of jambu is similar to the results for lettuce in hydroponic system obtained by Mahlangu *et al*. (2016), who did not observe significant effects of N increase on RFM and RDM. Similar behavior was also described by Pôrto *et al*. (2012), who found that N concentrations in the nutrient solution did not influence lettuce growth and production variables.

SFM was influenced by the treatments, increasing linearly as the N concentration in the nutrient solution increased, with greater increment (105.9 g plant^{-1}) at the dose of 21 mmol L^{-1} (Figure 1a), because N is the nutrient most demanded by plants, especially by leafy vegetables (FILGUEIRA, 2013), due to its participation in the synthesis of amino acids, proteins and pigments, such as chlorophyll (TAIZ *et al.*, 2017), hence being closely related to physiological activities that are important for growth and production such as photosynthesis.

Similar responses are verified when comparing these data with those of studies that analyzed the shoot biomass accumulation of vegetables as a function of N supplementation in different cultivation systems. Costa *et al*. (2020) and Rodrigues *et al*. (2014), evaluated the effect of N fertilization in soil on jambu production and observed increases in shoot biomass as the N doses increased. Effects of variation in N supply on chicory in hydroponic system were also reported by Cecílio Filho *et al*. (2017), who verified an increase in shoot fresh mass up to a certain dose in solution, which was explained by a quadratic function. It is worth pointing

Figure 1 – Shoot fresh mass (a), shoot dry mass (b), inflorescence fresh mass (c) and inflorescence dry mass (d) of jambu plants as a function of increased nitrogen concentration in nutrient solution. ** significant at 1% probability level; * significant at 5% probability level by t-test. Belém, Pará, 2019. Vertical lines are standard errors (n = 8)



out that, for jambu, there is the possibility of increase in N concentration in solution, since the highest yield was obtained at the highest concentration tested (21 mmol L^{-1}).

Thus, the increase in shoot biomass observed in this study for jambu with the increase in N supply, as well as by other authors in soil (BORGES *et al*., 2013; COSTA *et al*., 2020; RODRIGUES *et al*., 2014; SOUTO *et al*., 2018), is related to the functions performed by N in plant growth and development processes, composing all amino acids and consequently proteins and enzymes related to plant metabolism (MARSCHNER, 2012).

As for SDM, a linear accumulation was observed as the N concentration in the nutrient solution increased, with an increment of approximately 21% when the highest concentration (21 mmol L^{-1} of N) was compared with the lowest concentration (11 mmol L^{-1} of N) (Figure 1b).

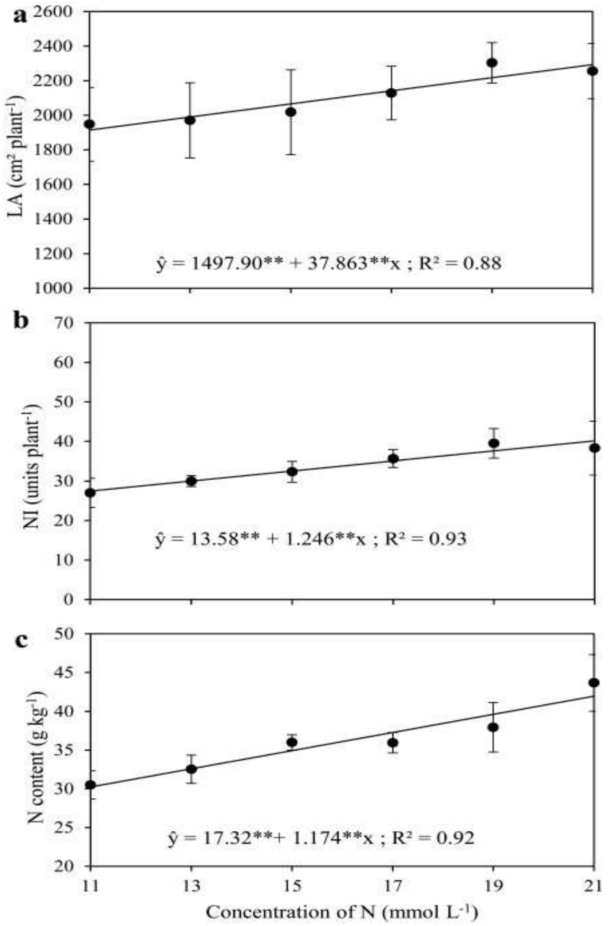
The increase of N in the nutrient solution promoted higher shoot dry mass for lettuce (MAHLANGU *et al.*, 2016), chicory (CECÍLIO FILHO *et al.*, 2017), and cauliflower (MASHABELA *et al.*, 2018), and these results were explained by quadratic functions, that is, up to a certain level of N there are reductions in dry mass accumulation rates in these crops, indicating that, under the conditions in which the present study was conducted, jambu may also show the potential to express positive responses regarding dry biomass accumulation at N concentrations greater than 21 mmol L^{-1} in the nutrient solution.

For IFM and IDM, there were linear increments with the increase in N concentration, equal to 32 and 37%, respectively, when the highest concentration (21 mmol L^{-1} of N) is compared with the lowest concentration (11 mmol L^{-1} of N) (Figure 1c and 1d).

The results obtained corroborate those reported by Rodrigues *et al.* (2014), who verified positive linear models for IFM and IDM as a function of the N doses applied in soil cultivation system. Costa *et al.* (2020) observed increasing accumulation in the fresh and dry mass of inflorescences of yellow flower jambu as N availability in the soil increased, regardless of the application of limestone in the soil. Peçanha *et al.* (2019), observed that N is the nutrient with the highest accumulation in inflorescences of jambu plants. This may be related to the high mobility of N in the phloem, facilitating its transport to sink organs, as is the case of inflorescences, highlighting its contribution to the production of these organs.

Similar to what was observed for biomass variables, the N concentration in the nutrient solution promoted linear increments in LA, NI and N content, which were described by linear models (Figure 2).

Figure 2 - Leaf area (a), number of inflorescences (b) and N content (c) of jambu plants as a function of increased nitrogen concentration in the nutrient solution. ** significant at 1% probability level; * significant at 5% probability level by t-test. Belém, Pará, 2019. Vertical lines are standard errors (n = 8)



The application of N in nutrient solution increased the expansion of the leaf area of jambu plants, leading to an average increase of 308.236 cm² $plant^{-1}$ at the dose of 21 mmol L^{-1}, in comparison to the dose of 11 mmol L^{-1} (Figure 2a). Increment in leaf area as the N concentration in the nutrient solution increased was also observed by Mahlangu *et al*. (2016) in lettuce crop. Similarly, Mampholo *et al*. (2018), evaluated the effect of N concentrations in the nutrient solution on the growth characteristics of three lettuce varieties and observed that N supplementation promoted a significant increase in leaf area, regardless of the tested variety. The expansion of leaf area, as demonstrated in this work, can be explained by the structural function performed by N, as in the formation of proteins and amino acids, being fundamental for the formation of essential compounds for plant metabolism and processes such as photosynthesis (TAIZ *et al*., 2017).

In relation to NI, it was observed that the increase in N concentration was explained by an increasing linear model, with an increase of 11 inflorescences plant^{-1} at the dose of 21 mmol L^{-1}, compared to the dose of 11 mmol L^{-1} (Figure 2b), which shows the importance of N in maintaining crop yield in both vegetative and reproductive stages, since both inflorescences and stems have potential for commercialization (GUSMÃO; GUSMÃO, 2013; SAMPAIO *et al*., 2018). Results obtained by Rodrigues *et al*. (2014) and Peçanha *et al*. (2019), point to the importance of N for the reproductive stage of jambu.

Regarding the N content in jambu leaves, as observed for most variables, its increase was explained by an increasing linear model, with the highest content (43.68 g kg^{-1}) obtained at the concentration of 21 mmol L^{-1}. The relationship between N fertilization and N accumulation in jambu plants was demonstrated by Borges *et al.* (2013), who observed increasing N accumulation in jambu leaves with the increase in urea doses in the soil.

When there is considerable amount of N in the system for absorption, as occurs in nutrient solutions, the plant tends to absorb it at levels higher than its requirement, storing it in the vacuole in the form of NO_3^- (MARSCHNER, 2012). Thus, such behavior may explain the relationship between the highest N content obtained with the highest N concentration (21 mmol L^{-1}) tested in this experiment. In addition, it is observed that the variations in N content in the leaves were related, in terms of behavior, to the growth and production characteristics of jambu, and the highest content obtained with the N concentration of 21 mmol L^{-1} led to a greater response in these variables.

It is worth pointing out that plants grown at the concentration of 11 mmol L^{-1}, which obtained average N contents of 30.5 g kg^{-1}, showed symptoms of N deficiency. Peçanha *et al.* (2019), observed N deficiency in jambu plants with average content in the leaves of 26.58 g kg^{-1}. Thus, as observed by Peçanha *et al*. (2019), in this study the symptomatology of N nutritional deficiency started with yellowing of the older leaves, which evolved to a generalized chlorosis and, over time, was evenly distributed in all leaves. This occurred probably because N is a nutrient that has high mobility in the phloem of plants and, when in deficiency, is easily redistributed from older leaves to younger leaves, which are initiating their metabolic processes (TAIZ *et al.*, 2017).

Not only the growth and production characteristics were influenced by the N supply in the nutrient solution, but also the quality variables such as TSS, TA and TSS/TA, except for pH, which averaged 6.5 (Figure 3).

As for TSS, it can be observed that the increase in N concentration led to a linear increase in the percentage of TSS in the plant from 6.0% at the N concentration of 11 mmol L^{-1} to 6.9% at the highest concentration (21 mmol N L^{-1}) (Figure 3a), values that are above those recommended by Chitarra and Chitarra (2005) for leafy vegetables (2 to 5%).

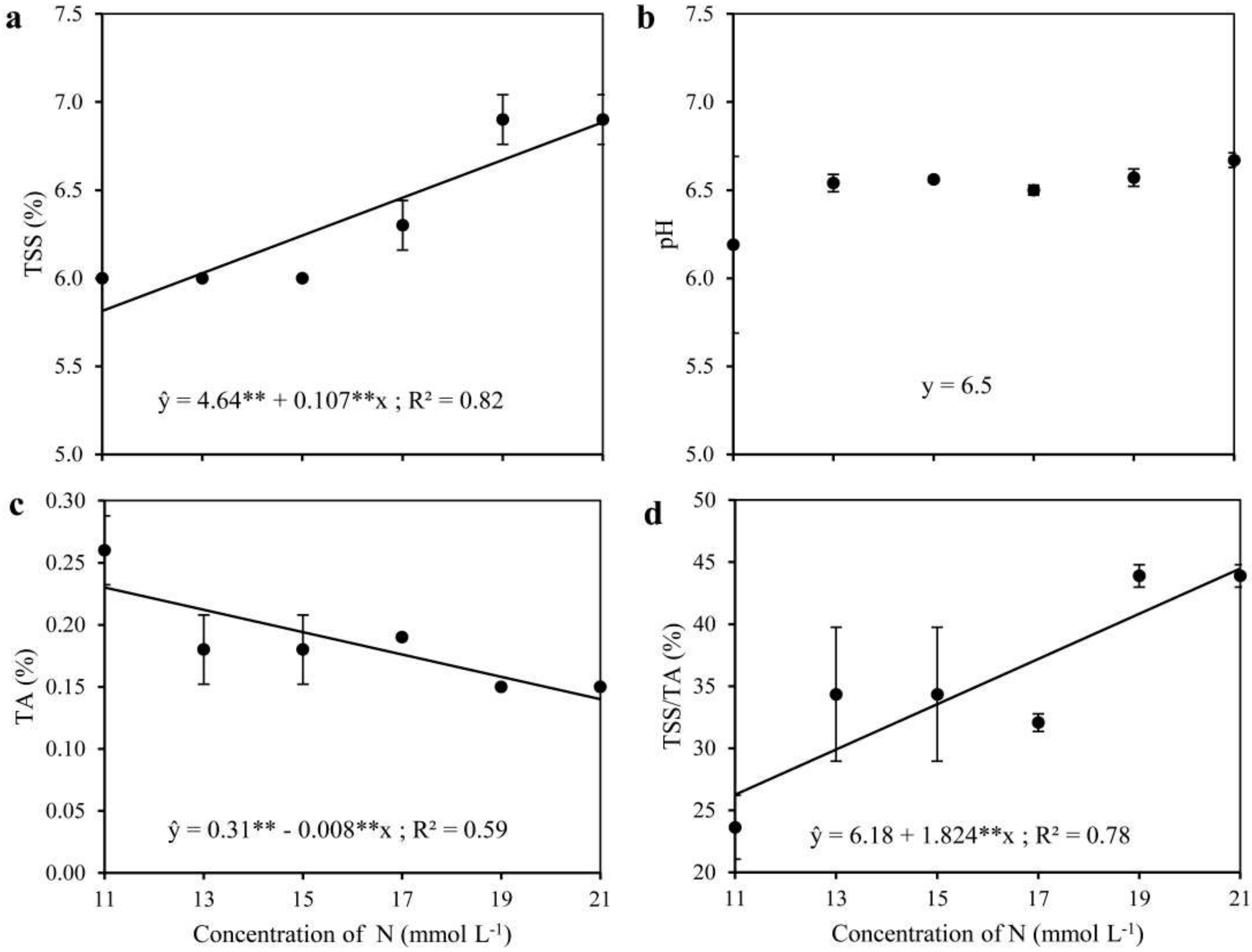
According to Wang *et al.* (2007), this result may be indirectly related to higher N contents in the plant, which promotes a higher rate of photosynthetic activity, resulting in higher production of photosynthates that can be stored as reducing sugars. Taiz *et al*. (2017), also highlight the importance of N cycle activity in chloroplasts for the production of photoassimilates. For crops such as lettuce, the increase of TSS is directly related to longer shelf life (REIS *et al*., 2014).

TA, contrary to the other variables, decreased with the increase of N concentration in the nutrient solution, being explained by a negative linear function. The highest acidity (0.26%) was observed at the N concentration of 11 mmol L^{-1} (Figure 3c). The increase in the concentration of oxalate, a predominant acid in jambu plants (OLIVEIRA *et al*., 2017), is a factor that interferes in the palatability of leaves; in this context, the decrease in the levels of this acid promoted by the increased N concentration in the solution is a desirable characteristic (CHITARRA; CHITARRA, 2005).

Regarding the absence of fits in the pH values in response to the different N concentrations in the solution with the TA values, it can be explained by the natural buffer systems generally found in vegetables, which are acidified by organic and/or inorganic acids until the system is fully saturated, thus resulting in the absence of variation in pH (DAMODARAN, 2010). Thus, despite the reduction in the content of acids, there was possibly a compensation in the buffering capacity through the higher production of compounds such as amino acids and proteins, which are influenced by the N supply in plants (NOKERBEKOVA; SULEIMENOV; ZHAPAYEV, 2018). According to Chitarra and Chitarra (2005), the acids found in the plant, either free or esterified, when in the presence of their potassium salts produce a small variation of pH due to the balance of the system, even if there are variations in titratable acidity.

As for the TSS/TA ratio, there was a linear increase as the N concentration in the nutrient solution increased, with a significant increase of 86% when the highest N concentration (21 mmol L^{-1}) was compared to the lowest concentration (11 mmol L^{-1}) (Figure 3d). This parameter is related to the evaluation of flavor, showing greater proportion of sugars to the detriment of acidity, that is, the higher the TSS/TA ratio, the more pleasant the taste, representing an excellent combination between sugars and acids; however, low values represent predominance of acids, which gives a less pleasant flavor (CHITARRA; CHITARRA, 2005). Based on these results, the positive relationship between the quality parameters in jambu

Figure 3 – Total soluble solids (a), hydrogen potential (b), titratable acidity (c) and total soluble solids to titratable acidity ratio (d) of jambu plants as a function of increased nitrogen concentration in the nutrient solution. ** significant at 1% probability level; * significant at 5% probability level by t test. Belém, Pará, 2019. Vertical lines are standard errors (n = 8)



plants and adequate concentrations of N in the solution in hydroponic system, as well as in the maintenance of growth and production of the crop, as observed in the present study, is noticeable. Results obtained by Peçanha *et al*. (2019), showed that, among the macronutrients, N was the one that promoted the greatest restriction on the growth and production characteristics of jambu when it was omitted in the nutrient solution.

CONCLUSIONS

Variation of N concentration in the nutrient solution does not affect the variables MSL, D, RFM, RDM and pH. However, it causes effect on the other growth, production and postharvest quality variables analyzed, and the N concentration of 21 mmol L^{-1} in the nutrient solution is the most indicated to obtain better performance of jambu plants.

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