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RESEARCH ARTICLE

Production and quality of 'Pérola' pineapple under fertigation

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ABSTRACT

The aim of this paper is to evaluate the yield and quality of 'Pérola' pineapple under increasing rates of nitrogen and potassium applied through fertigation. The experiment was conducted in a randomized block design, with four replications, in a factorial scheme (4x4), which represents four nitrogen rates (128, 256, 384 and 512 kg ha^{-1} of N) and four potassium rates (192, 384, 576 and 768 kg ha^{-1} of K_2O) via fertigation. The evaluations consisted of physical and chemical fruit characteristics and yield. Increasing nitrogen rates provided linear growth on fruit production features and the rate of 516 kg ha^{-1} resulted in fruits with the largest diameters. The highest total yield on 'Pérola' pineapple crop was reached on plants under the supply of 498 kg ha^{-1} of K_2O. Rates between 523 and 583 kg ha^{-1} of K_2O, provided the largest fruit matter and the highest fruit pulp yield. The increasing amount of nitrogen applied by fertigation resulted in linear growth on fruit pulp pH, though it did not influence the soluble solids content. The lower acid content and higher SS/acid ratio on fruits were reached with the N rates of 333 and 375 kg ha^{-1} respectively.

Keywords: *Ananas comosus* (L.) Merrill; mineral plant nutrition; physical-chemical characteristics

INTRODUCTION

The pineapple crop (*Ananas comosus var. comosus* L. Merril) is original from the Tropical and Subtropical America. It is an important commodity for Brazilian economy, due to its attractive fruit that can be consumed either fresh or processed (Oliveira-Cauduro et al., 2016). In Brazil, the pineapple varieties most planted are 'Pérola' (80%), followed by 'Smooth Cayenne', 'Jupi' and 'Gold' (MD-2) (Venâcio et al., 2017).

On the state of Espírito Santo, the predominant pineapple variety is still the Pérola, mostly planted in the southern region of the state, with emphasis for the city Marataízes (main producer), Presidente Kennedy and Itapemirim. The expansion of pineapple plantation on the state, mainly on northern region, has become a valuable alternative to diversify fruit production in the region (Palomino et al., 2015).

Although the pineapple crop is resistant to rainfed cultivation, increasing producers in Brazil has planted pineapple under irrigated systems, both on traditional areas and on places with new plantations. On tropical regions, the irrigation has been used to complement the water demand of the plants, especially on dry seasons (Silva et al., 2017).

Furthermore, the use of fertilizers can have a direct influence on the mineral composition and nutrients extraction by the plant. Venâncio et al. (2017) found that the 'Vitória' pineapple crop showed low initial nutrients extraction followed by high extraction at the moment of flowering induction. García et al. (2017) reported that restrictions on soil fertility, affect the yield and quality of pineapple fruits. Thus, the use of fertigation, that is, the use of fertilizers through irrigation water, might be beneficial for pineapple producers, especially in areas with drip irrigation, once this system enables precise applications of fertilizers at the moment of plants higher demand, which enables greater yield and better fruit quality.

Among the essential nutrients for plants, potassium and nitrogen are required in larger quantity for pineapple

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crop. They perform isolated and/or associated important functions on nutritional aspects of the plant, which directly influence the vegetative growth, yield and fruit quality (Rodrigues et al., 2013).

This study was therefore conducted to evaluate the yield and quality of 'Pérola' pineapple crop under increasing rates of nitrogen and potassium applied through fertigation.

MATERIAL AND METHODS

The experiment was carried out on the Experimental Farm of the Federal University of Espírito Santo- CEUNES/UFES, located in São Mateus, northern region of Espírito Santo state, Brazil, 18º40'32"S and 39º51'39"W. The city has an altitude of 37.7 m, and has a tropical climate with dry winter, characterized as Aw (Köppen) according to Pezzopane et al. (2010), with annual average temperature of 23.8 °C and precipitation of 1,212 mm. The weather variables (Fig. 1) during the period of the experiment (April/16 – June/17) were recorded by means of an automatic meteorological station, located nearly 200 meters from the field.

The pineapple variety (*Ananas comosus var. comosus* L. Merril) chosen was the 'Pérola' (Fig. 2), and the vegetative propagation material used was derived from a previous experiment conducted near the site, with matrices plants of 18 months. The seedlings were made from slips, selected according to size and absence of diseases (average size 30 cm).

Planting was carried out in April 2016, by furrow with a depth of approximately one-third of the seedling length. The seedlings were treated with fungicides and insecticides, to prevent the main pests and crop disease. Throughout the plant cycle, the necessary agricultural practices were carried out, such as weeding and pests and diseases control.

Soil characteristics measured according to Embrapa's methodology (2011), are presented on Table 1. The soil was previously treated with lime, using dolomitic limestone (CaO-32%, MgO-14%, PRNT-86,11%) and raising the base

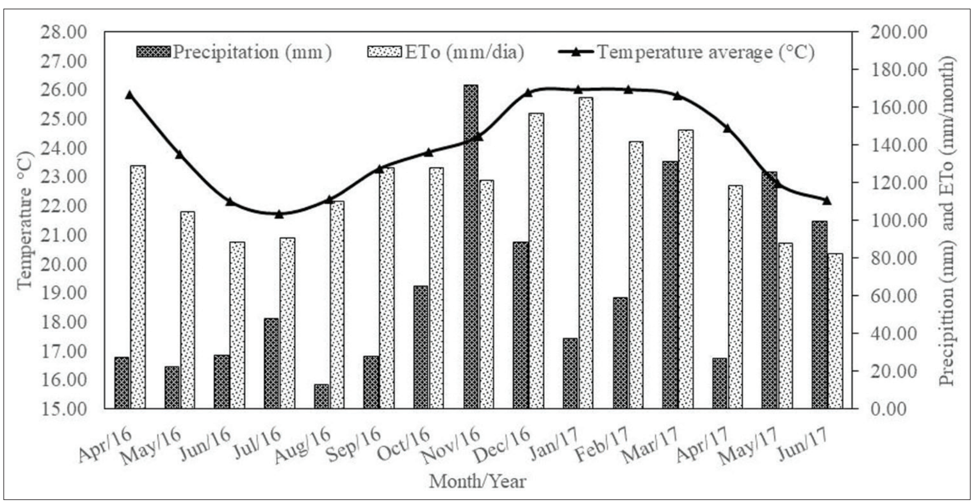

Fig 1. Temperature average, precipitation and ETo during the period of the experiment (Planting: April/16, Harvested: June/17).

Fig 2. The pineapple variety (*Ananas comosus var. comosus* L. Merril) chosen was the 'Pérola' of the experiment was carried out on the Experimental Farm of the Federal University of Espírito Santo- CEUNES/UFES, located in São Mateus, northern region of Espírito Santo state, Brazil.

Table 1: Soil chemical and phyisical characterization in the experimental area

Parameters evaluated	Unit	0.00-0.20 (m)
Phophorus Mehlich[1/]	mg dm^{-3}	7.00
Potassium (K)[1/]	mg dm^{-3}	45.00
Sulfur (S)[2/]	mg dm^{-3}	8.00
Calcium (Ca)[3/]	cmolc dm^{-3}	1.50
Magnesium (Mg)[3/]	cmolc dm^{-3}	0.50
Aluminium (Al)[3/]	cmolc dm^{-3}	0.30
pH in H_2O[4/]	-	5.40
Organic Matter[5/]	dag kg^{-1}	2.10
Iron (Fe)[1/]	mg dm^{-3}	166.00
Zinc (Zn)[1/]	mg dm^{-3}	0.20
Copper (Cu)[1/]	mg dm^{-3}	0.50
Manganese (Mn)[1/]	mg dm^{-3}	5.00
Boron (B)[6/]	mg dm^{-3}	0.58
Sodium (Na)[1/]	mg dm^{-3}	21.00
Effective CEC (t)	cmolc dm^{-3}	2.50
CEC at pH 7.0 (T)	cmolc dm^{-3}	5.00
Bases saturation	%	44.10
Coarse sand	g kg^{-1}	654.00
Fine Sand	g kg^{-1}	182.00
Clay	g kg^{-1}	135.00
Silt	g kg^{-1}	30.00

[1/]Extraction: HCl 0.05 mol L^{-1}+H_2SO_4 0025 mol L^{-1}; [2/]Extraction: Ca $(H_2PO_4)_2$ 001 mol L^{-1}; 3/Extraçtion: KCl 1.0 mol L^{-1}; [4/] pH in H_2O 1:2.5; [5/] Oxidation: $Na_2Cr_2O_7$ $2H_2O$ + 4.0 mol L^{-1} H_2SO_4 10.0 mol L^{-1}; [6/] Extraction: $BaCl_2$ $2H_2O$ 0.125

saturation to 60%, being to apply 0.462 t ha^{-1}. The pineapple plants received mineral phosphate fertilizer on planting furrows, 120 kg ha^{-1} of P_2O_5, based on Almeida & Souza (2011).

Top dressing fertilization was performed by fertigation, applied weekly and with increasing rates, as described by Almeida & Souza (2011), totaling the amount of fertilizer stablished for each treatment. The following sources of macronutrient were utilized: Nitrogen (urea, with 45% of N), phosphorus (single superphosphate, with 18% P_2O_5) and potassium (potassium chloride, with 58% K_2O). The most important micronutrients for pineapple plants, iron, zinc, copper and boron, were supplied in the planting furrow, with the FTE BR 12 fertilizer, applying 50 kg ha^{-1}.

Ten months after planting, through observations of the size of leaf "D", the plants were submitted to flowering induction using Ethephon based product (2-chloro ethyl phosphonic acid), applied into the heart of pineapple plant (50.0 ml/plant). The formulation applied was 1.50 ml p.c/liter of water + urea at 2% of the commercial product + 0.30-0.35g of Ca $(OH)_2$ per liter of cold water (Reinhardt & Cunha, 2000), being applied early in the late afternoon under stable weather conditions.

The experiment was carried out in a randomized block design, with four replications, in a factorial scheme (4x4). The treatments were four nitrogen (N) rates 128, 256, 384 and 512 kg ha^{-1} of N applied via fertigation, which represents 40, 80, 120 and 160% of recommended rates; and four potassium (K_2O) rates 192, 384, 576 and 768 kg ha^{-1} of K_2O via fertigation, which represents 40, 80, 120 e 160% of recommended rates for soils with low K availability (Almeida & Souza, 2011). The doses were applied during the development of the crop being parceled during the cycle according to Almeida & Souza 2011.

The experimental plots were composed of rows 4.80 m long, 5.20 m wide, with 3.85 plants per square meter (38,500 plants per hectare), totaling 96 plants per plot. At planting, conducted in April 2016, a double rows system was used at a spacing of 1.00 x 0.30 x 0.40m, within the total experimental area of 2,000 m², including borders.

The irrigation system used on the experiment was the drip irrigation. Irrigation depths were calculated based on the restitution of crop evapotranspiration (ETc) estimated by means of soil water balance (Bernardo et al., 2008) in a control volume corresponding to a depth of 0.40 m, where most of pineapple roots are. The reference evapotranspiration (ETo) was estimated by the Penmann-Monteith equation, according to Allen et al. (1998).

To calculate the ETc, single crop coefficients (Kc) were used according to plant stage of development: initial stage, Kc = 0.40; secondary stage, Kc = 0.80; production stage, Kc = 1.00 and maturation, Kc = 0.45 as proposed by Souza & Torres (2011).

For the introduction of the soluble fertilizers to the irrigation system was used the flow bypass tank type injector with volume of 7.0 liters. The devices were installed in parallel to the irrigation tubing at the entrance of each treatment. The fertilizers urea (N) and potassium chloride (K_2O) were diluted, filtered and then injected into the irrigation lines through the flow bypass tank type injector, were built by the executing team from segments of PVC pipes DN 150 and connectors, one injector for each treatment.

At the end of the fourteenth month after planting and 120 days after flowering induction, the fruits were manual harvested at the point of maturation known as "colored", which presents up to 50% individual fruitlets with yellow color. They were also selected by size and exemption from pests and diseases. Then, they were packed in plastic harvest boxes, and immediately transported to the laboratory and washed in running water for residues removal, as recommended by Antoniolli et al. (2005).

To evaluate the physical characteristics of fruits, a sample of 20 fruits per treatment was collected, being evaluated:

fruit length with and without crown; diameter of fruit; crown length, determined with centimeter graduated scale; average mass of fruits (g); average mass of crowns (g); mass of fruit pulp (g), determined by individual fruit weighing on a scale. The mass of crowns was obtained by the difference between mass of fruits with and without crown. The percentage of pulp (%) was calculated by the average mass of fruit pulp/mass of fruits without crown ratio. The total e pulp yield (kg ha^{-1}) was obtained from the mass of fruits with and without crown multiplied by planting density (kg ha^{-1}).

From the sample of 20 fruits five were removed for chemical evaluation, and pH determined with a benchtop digital pH meter calibrated with buffer solution of pH 7.00 and 4.00. The solid soluble (SS) determined in ºBrix was performed using digital refractometer, taking two drops of pineapple juice. The titratable acidity was obtained by the titration method with 0.10 N NaOH and the data are expressed as a percentage of citric acid, and the ratio, by the SS/Acidity, determined according to the Adolfo Lutz Institute (IAL, 2008).

The results were analyzed with analysis of variance (ANOVA), with effects unfolding, according to their significance. The choice of the regression model was based on the model of greater significance by the test F, which deviation of the regression was not significant.

RESULTS AND DISCUSSION

For the physical and chemical characteristics of fruits no significant interaction N K versus only its isolated effect for each nutrient. Evaluating the physical characteristics of fruits, it was observed a linear association between the potassium rates and length of fruits without crown, and a quadratic association with increasing rates of nitrogen, being the application of 450 kg ha^{-1} of N the rate that provided the maximum length (19.96 cm) (Fig. 3A), already for potassium there was a linear increase of 6.8%, which may be related to an improvement of the physiological activities of the plant with increased levels of potassium, resulting in fruits with larger size, since potassium plays an important role in metabolic reactions of various physiological processes. This result was similar to that found by Ribeiro (2016), who observed lengths of the fruits without crown varying from 17.70 to 20.17 cm in experiment with pineapple 'Pérola'. According to the same author, the development of fruit mass and the length of crown influence the fruits length, because theoretically, higher mass and length of crown can cause smaller length on pineapple fruits or vice versa.

For the length of fruit with crown, there was no effect of potassium rates (Fig. 3B). However, when analyzed the effect of nitrogen rates, the fruits presented linear increase. This positive association was not related to the growth of crown, but to the fruits itself, since the opposite was observed to crown length, in which increasing nitrogen and potassium rates resulted in a decrease of 6.55% and 9.34% respectively in crown length (Fig. 3C).

This decrease in crown length may be related to the redirection of nutrients targeting fruit formation. This situation can be verified on Fig. 3D, which the behavior of fruit length with and without crown were linear and the

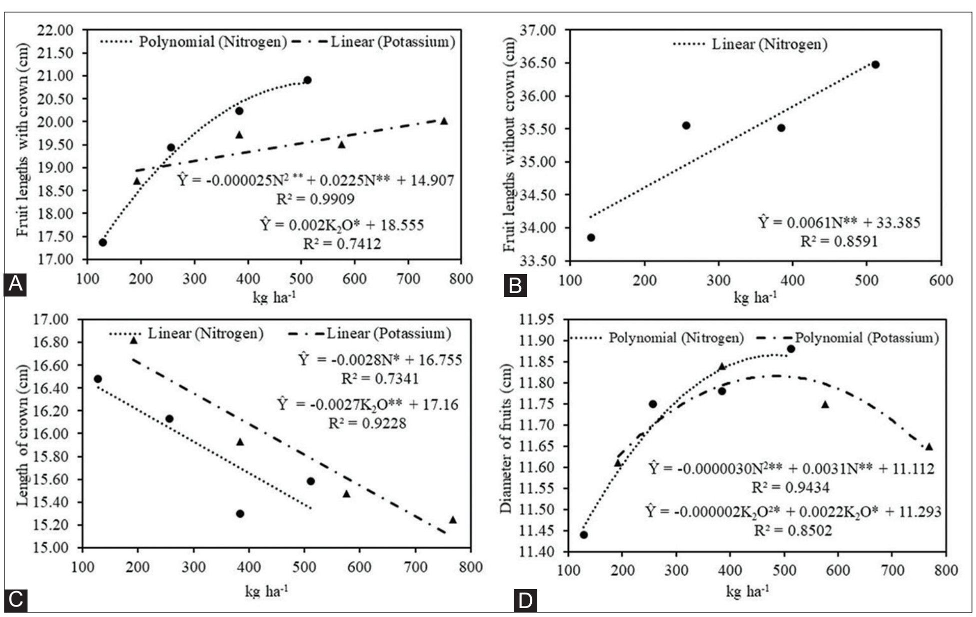

Fig 3. Fruit lengths with crown (A) without crown (B), length of crown (C) and pineapple diameter (D) of 'Pérola' pineapple fertigated under different doses of nitrogen and potassium. * **coeficiente de regressão significativo a 5% ou 1% respectivamente pelo teste t.

diameter of the fruit had a quadratic association with the increasing rates of potassium, with the highest value for 550 kg ha^{-1} of K_2O (11.89 cm), and linear behavior nitrogen to these variables, showing that this nutrient was decisive in the vegetative development of the plant, which in turn led to greater fruits with lower crown. These results differ from Rios et al. (2018), working with ‹Imperial› pineapple observed a linear increase for the diameter of the fruit in relation to the rates of potassium applied on soil.

Reduction of crown length on pineapple fruits with increasing N and K_2O rates, was also reported by Rios et al. (2018). The authors concluded that the reduction of the crown is a desired factor when there is an increase in the infructescence and for fruits destined to exportation, once the ideal crown length is between 5.00 and 13.00 cm, due to the standardization of packages. However, in this study, a mean crown length of 16.10 cm was found, corroborating with Guarçoni and Ventura (2011), who reported that the market requirement defines the amount of nitrogen to be applied, which will result in fruits with higher or lower crowns, which in this study increased nitrogen levels afforded lower crowns.

The average mass of fruits, pulp as well as total and pulp productivity (Fig. 4A, 4B, 4C and 4D) had a linear increase nitrogen rates, which agrees with Caetano et al. (2013) and Silva et al. (2015) who reported that the increment of nitrogen rates increase the size of the fruits, promoting greater yield.

According to Darnaudery et al. (2018), nitrogen is essential to maintain high growth rates. This suggests that the response of pineapple crop to nitrogen fertilization is strong, allowing high yields with short growth cycles. Isuwan (2014) suggests that this is due to the higher plants growth, which can support the increase in fruit production, resulting in a highly positive relationship between the plant mass and fruit mass.

When analyzed the yield in relation to the potassium rates, the data shows a quadratic association, with a maximum point at the rates of 583 for average fruit mass (1,631g), 523 for pulp mass (1,161 g), 498 for total yield (66,966.66 kg ha^{-1}) and 542 kg ha^{-1}of K_2O for total pulp (45,082.00 kg ha^{-1}) (Fig. 4A, 4B, 4C and 4D).

According to the results, the mass of the fruit is within the established for the external market, in which the mass of the pineapple must be between 700 and 2,300 g. Fruits very small (mass less than 700 g) and very large (greater than 2,300 g) have low commercial value for fresh consumption and may be benefited in juice or sweet industries (Vilela et al., 2015).

Lower results for yield were found by Rodrigues et al. (2013) who studied the effect of different K/N ratios on ‘Pérola’ pineapple crop under the climatic conditions of Coastal Plains on Paraíba state. The authors found that K and N rates in 2:1 ratio (900 and 450 kg ha^{-1}) resulted in higher mean fruit mass values (1.38 kg). However, Berilli et al. (2014) comparing qualitative attributes of four pineapple varietie (‘Vitória’, ‘Pérola’, ‘Gold’ and hybrid EC-93) for fresh consumption, found values of fruit mass (1,039 g), pulp (629 g) and yield (40,600.00 kg ha^{-1}) for the ‘Pérola’, lower than the values found on this paper.

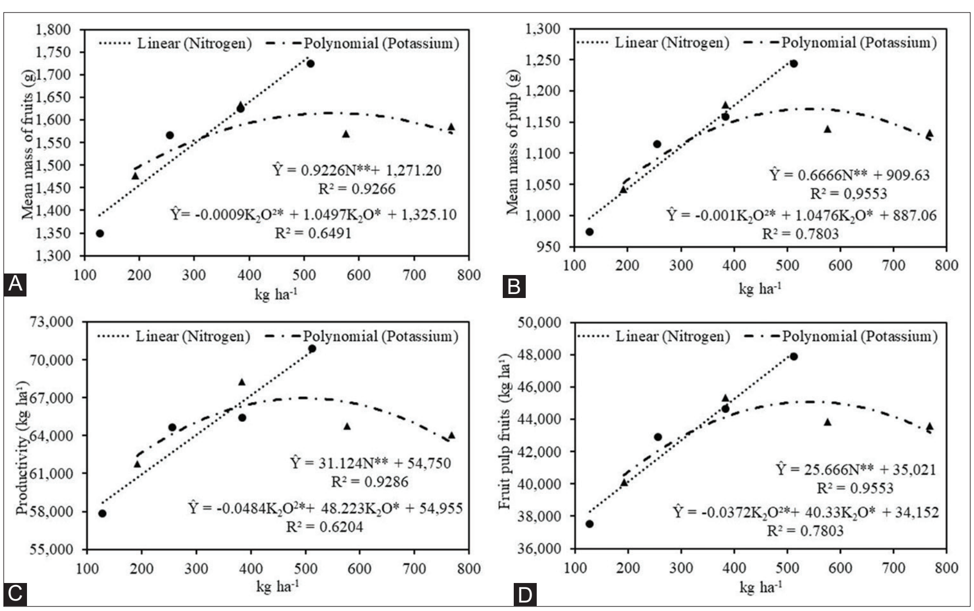

Fig 4. Mean mass of fruits (A) and pulp (B), productivity (C) and fruit pulp yield (D) of ‘Pérola’ pineapple fertigated under different doses of nitrogen and potassium. * **coeficiente de regressão significativo a 5% ou 1% respectivamente pelo teste t.

Considering that the Pérola genotype is intended for fresh consumption, the mass and productivity of fruit pulp become important, where 71% of fruit mass was pulp. Others studies also reported the responsiveness of pineapple plants to potassium fertilization, as Teixeira et al. (2011), Garçoni and Ventura (2011) and Spironello et al. (2004), who reported the effect of potassium rates increase in on the fruit mass of different pineapple varieties.

The highest percentage of fruit pulp in response to potassium fertilization may be related to the increase of potassium availability on soil since the potassium content of the soil was medium (Table 1), showing that increases with the potassium in the soil through irrigation favored the production of pineapple pulp Pérola genotype. In addition, it may be related to the function that the nutrient exerts on the plant, once K is important for increasing the translocation of carbohydrates, it improves the efficiency of water use and improve nitrogen fertilization (Marschner, 2012). According to Rodrigues et al. (2016), potassium is important in fruit filling, resulting in larger and heavier fruits due to its important function in the transport of photoassimilates from the leaves to the fruits and the expansion of the cells, resulting in higher productivity.

The pH of fruit pulps showed a linear behavior in relation to the nitrogen rates applied (Fig. 5A). Increasing nitrogen rates, using urea as a source, may provide higher NH_4^+ availability, which leads to greater accumulation of mineral acids and dilution of organic acids, resulting in an increase in pH, as reported by Asuncion et al. (2018) that worked with different sources and rates of nitrogen in *Solanum lycopersicum*.

The acidity presented quadratic behavior reaching a minimum point (0.30 % of citric acid) when applied 333 kg ha^{-1} of N (Fig. 5B). This result can be explained due to the production of larger fruits as applied increasing nitrogen rates, causing dilution of titratable acidity (TA) as reported by Silva et al. (2015), and reaching a minimum point.

The SS/TA ratio showed a quadratic behavior, with maximum point when applied 375 kg ha^{-1} of N (Fig. 5C). This might be related to the consumption of organic acids and SS increment, since according to Ettienne et al. (2013), N may have an indirect impact on the production of these organic acids, due to the stimulus to vegetative growth, which causes fruit shading (with reduction of temperature and perspiration), or diversion of assimilated fruits to vegetative growth, which may have negatively affected the production of organic acids, with a consequent decrease in TA.

Due to the possible limitation of production of organic acids, the potassium rates applied did not influence the pH, acidity and SS/acid ratio, which can be explained since K^+, in general, move in the phloem in the company of an anion, such as organic acids, due to the limitation of these acids, there was no modification in the TA, in response to K_2O. The soluble solids had no influence of the increasing rates of neither potassium nor nitrogen, with an average of 13.51 ° Brix. This value is within the norms for classification of pineapple fruits, in which the fruit can be considered mature when SS is above 12.00 ° Brix. This value of SS, according to Pereira et al. (2009), is within the national values for good quality fruits for fresh consumption.

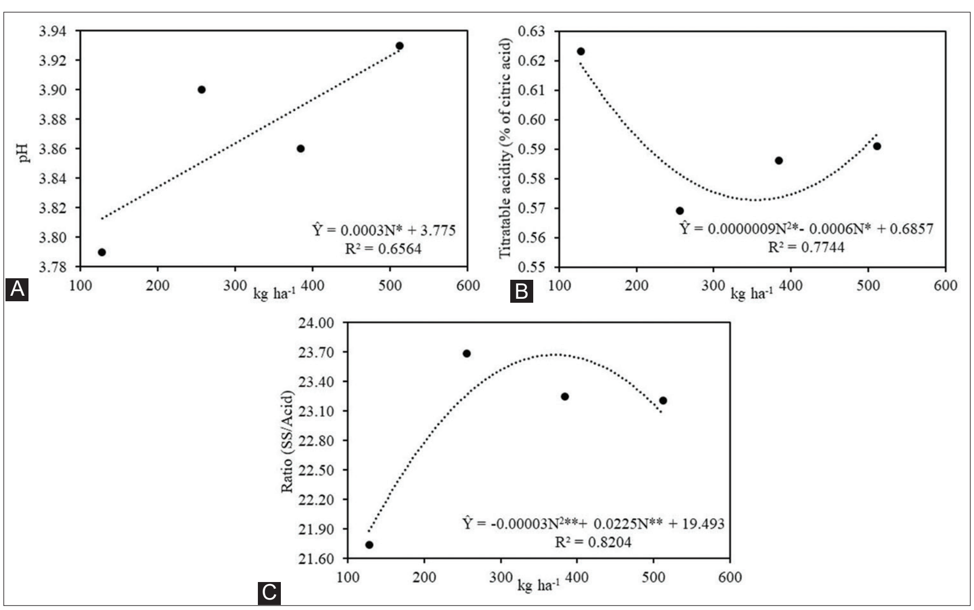

Fig 5. 'Pérola' pineapple fruit characteristics in function of nitrogen (N) doses applied through fertigation: pH (A); titratable acidity (B) and ratio (SS/acid) (C). * **coeficiente de regressão significativo a 5% ou 1% respectivamente pelo teste t.

The results of this work demonstrate its importance, since the need to research more about the effect of mineral elements on the quality of the fruits of pineapple, results agree with Aular et al. (2014) repots, which claim that the N can affect or not the fruit mass, SS and TA; and K may affect or not fruit size, SS, TA and SS/AT.

CONCLUSION

Increasing nitrogen rates provide a linear increase in the fruit production characteristics and a rate of 516 kg ha^{-1} of N provided the largest fruit diameter.

The highest total yield on 'Pérola' pineapple crop was reached on plants under the supply of 498 kg ha^{-1} of K_2O. Rates between 523 and 583 kg ha^{-1} of K_2O provided the highest fruit mass, pulp mass and productivity.

Increasing amount of nitrogen applied through fertigation raised the pH on fruit pulp, though it did not influence the soluble solids content.

The lower acid content and higher SS/acid ratio on fruits were reached with the N rates of 333 and 375 kg ha^{-1} respectively.

The potassium rates did not influence any chemical characteristics of pineapple fruits.

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Authors' contributions

Authors 1, 2 and 3 designed the study, managed the writing of the manuscript and performed the statistical analysis. Authors 4 and 5 performed the evaluations of the parameters analyzed in the study. The author 6 managed the bibliographic searches. All authors read and approved the final manuscript.

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