Article

Banana bunching associated with climatic and nutritional variations

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Abstract

Choked banana presents closeness of petioles looks that allows the exit of the distal part of the inflorescence, but not the basal part is stuck up at the throat. The aim of this study was to avaluate the effect of choking on the growth of *Musa* spp. *cv* Nanica, as well as to investigate how the climatic variations and status nutritional of plants are associated whith this physiological disorder. The experiment was conducted in September/2018 in August/2019 in Registro, São Paulo state, Brazil. The experimental design adopted was completely randomized with two treatments and ten repetitions, in sub-divided plots over time (months). The evaluation consisted in determining the intensity of the symptom, number of leaves, plant height, hand number, stalk length, symptoms of nutritional deficiency and other abnormalities, leaf nutrient contents. Plant growth was not impacted by choking, only the hands number in the months of October/2018 and June/2019 to August/2019 ($p< 0.05$). Choking occurred throughout the year, with a predominance of severe symptoms of April in June due a redução da temperatura e radiation. The twisted fruits, united by fusion of floral parts and with different sizes occurred, respectively, in 21.67, 60.83 and 17.52% of the symptomatic plants, associated with the cool temperature during the differentiation of the female fruit. Choking and abnormalities in the bunch and fruits were associated with Zn deficiency ($p< 0.05$). The deficiency of Ca at low temperatures, the lower availability of radiation and the high relative humidity were also associated with the choking. The excess of P in the soil, as well, the adverse climatic conditions contributed to the limitation of these nutrients.

Keywords: *Musa* spp., abiotic stress, foliar obstruction, nutritional deficiency.

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Introduction

Banana (*Musa* spp.) is one of the most valuable global agricultural commodities, with commercial plantations responsible for supplying nearly 15 % of total global banana production (Panigrahi *et al.*, 2021). Although, banana has global socio-economic importance, as with any crop is threatened by biotic and abiotic constraints, resulting in significant economic and productivity losses, subsequently affecting food security (Pua *et al.*, 2019). Bananas are perennial herbaceous plants, grow and produce fruits all over the year (El-Mahdy and Eissa, 2018). Its floral development involves elongation of internodes of the true stem and its emergence through the cylindrical core formed by the leaf sheaths of the pseudostem (Panigrahi *et al.*, 2021).

A physiological disorder is observed in banana plants worldwide which include failure of the flowering stalk or bunch to emerge from the pseudostem due constriction, called obstruction floral, ‘arrepollamiento’ (Torres and Castillo, 2013) or choke throat (Ravi and Vaganan, 2016). Choked banana presents closeness of petioles looks that allows the exit of the distal part of the inflorescence, but not the basal part is stuck up at the throat. The rosette appearance (Ravi and Vaganan, 2016), reveal deficit of auxin and giberelin (Bahadur *et al.*, 2020), respectively, hormones responsible for phyllotaxis and stem alongation.

Choking symptoms appear under high or low temperature, drought and prolonged flooding (Torres and Castillo, 2013; Donato *et al.*, 2015; Ravi and Vaganan, 2016; Bahadur *et al.*, 2020; Nansamba *et al.*, 2020), extremely humid weather (Donato *et al.*, 2015) and extended period of cloudy weather (Robinson and Saúco, 2011). Nutritional deficiency may be associated with this physiological disorder (Robinson and Saúco, 2011; Torres and Castillo, 2013). Because they are required in the cell, structure or are associated with enzyme activity. Plant nutrients also play important functions for plants grown under stress conditions (Youssef and Eissa, 2017).

Some nutrients have a specific function in hormonal metabolism, which consequently makes them even more important for changes in the development and maintenance of functional integrity during stress. N, P and Zn deficiency were related to choking (Robinson and Saúco, 2011; Torres and Castillo, 2013). In the Vale do Ribeira, situated in southeastern Brazil, between the south of São Paulo and the north of Paraná state, there marginal tropical climate with grandes variações in temperature, radiation, precipitation between seasons. This makes it an interesting region for evaluate choking aiming at management strategies. The aim of this study was to avaluate the effect of choking on the growth of *Musa* spp. cv. Nanica, Cavendish group, AAA subgroup, as well as to investigate how the climatic variations and status nutritional of plants are associated whith this physiological disorder.

Materials and methods

Experimental conditions

The experiment was conducted in September 2018 at August 2019 at a farm commercial in Registro, São Paulo state, Brazil, located at 22º 29’ 37” south latitude and 47º 48’ 50” west longitude with an altitude of 80 m. ‘Nanica’ banana plants (*Musa* spp.) of group Cavendish and subgroup AAA in the 5th cultivation cycle were subject of the experiment. The production system was in single row at a spacing of 2.5 x 2.5 m. The climate in the region was categorized as tropical, without dry season (Alvares *et al.*, 2013).

The average annual maximum and minimum temperatures were 26.7 °C and 17.5 °C, respectively, and that the average annual rainfall was 1 615.4 mm. The soil of experimental ares is classified as Cambissol (Embrapa, 2013). The soil characteristics in August 2018, respectively, in layers 0-10 and 10-20 cm were presented in (Table 1). Cultural management, fertilization and phytosanitary control followed recommendations adopted in commercial banana production (Moreira, 1999).

Table 1. Soil chemical characteristics.

	pH CaCl	OM	P*	K	Ca	Mg	$S\text{-}SO_4^-$	Fe	Mn	Cu	Zn	B	Al^{+3}	CEC	V (%)
				(mmolc dm^{-3})				(mg dm^{-3})					(mmolc dm^{-3})		
0-20 cm	5.8	4	289	14.2	84	33	399	63	47	3.8	7.5	1.03	0	153.5	79
20-40 cm	5.7	3.7	282	12.7	79	32	350	49	33	2.9	6.5	0.84	0	138	82

OM= organic matter; CEC= cation exchange capacity; V= base saturation percentage; *= P in resin.

Experimental design

The experimental design adopted was completely randomized with two treatments and ten repetitions, in sub-divided plots over time (months). The treatments consisted of plants without symptoms and plants with symptoms of choking were chosen at random, monthly, for one year, at the beginning of flowering (newly opened bracts), in a uniform plot of 0.5 ha.

Assessments

The evaluation consisted in determining the intensity of the symptom (Figure 1), number of leaves, the height of the mother and daughter plant, number of hands in the bunch, the length of the stalk, symptoms of nutritional deficiency and other abnormalities in the bunch or fruits. To determine the intensity of symptoms, initially, 20 plants with symptoms of a plot of about 0.1 ha were photographed to establish a scale of symptom intensity (Figure 1). The mild symptom included only a slight change in phyllotaxis; moderate, phyllotaxis alteration with partial overlapping of the leaf blades, and severe, complete overlapping of the leaves and abnormality in the bunch or fruits.

For leaf nutrient contents (N, P, K, Ca, Mg, S, B, Cu, Zn, Fe and Mn), 10 cm of the medial part of the blade of from the third fully expanded leaf was taken, discarding the central vein. Leaf samples were washed, dried in forced air circulation oven at 60 °C ±5 °C and ground in a Willey type mill. Nutrient contents were determined according to Bataglia *et al.* (1983) and the reference value adopted according to Borges *et al.* (2006). Also were collected datas of climatics variables (global solar radiation, temperature, relative humidity and precipitation), in a meteorological station near the experimental area. The sky condition was estimated according to Iqbal (1983), from the clarity index (Kt) as clear, partly cloudy and cloudy.

Figure 1. Intensity of choking symptoms: A) absence; B) mild; C) moderate; and D) severe.

Statistical analysis

Data of analyses were expressed as means of five replicates. Statistical analysis was conducted with the Sisvar software (Ferreira, 2011). Mean comparisons were performed using the Tukey's test ($p< 0.05$). Correlation between variables was determinate by Pearson's coefficient.

Results and discussion

Effect of the choking on growth of plants

There was choking throughout the experimental period (Figure 2). In December 2018, all choked plants exhibited mild symptoms, while in April 2019 to June 2019, there was a high frequency of severe symptoms (Figure 2). Plant growth was not impacted by choking, as the growth in height of the mother plant (Figure 3A) and daughter plant (Figure 3B), stalk length (Figure 3C), leaves number at flowering (Figure 3D) did not differ between plants with and without symptoms. Only the number of hands per bunch in the months of October 2018 and June 2019 to August 2019 was lower in plants with symptoms ($p< 0.05$) (Figure 3E).

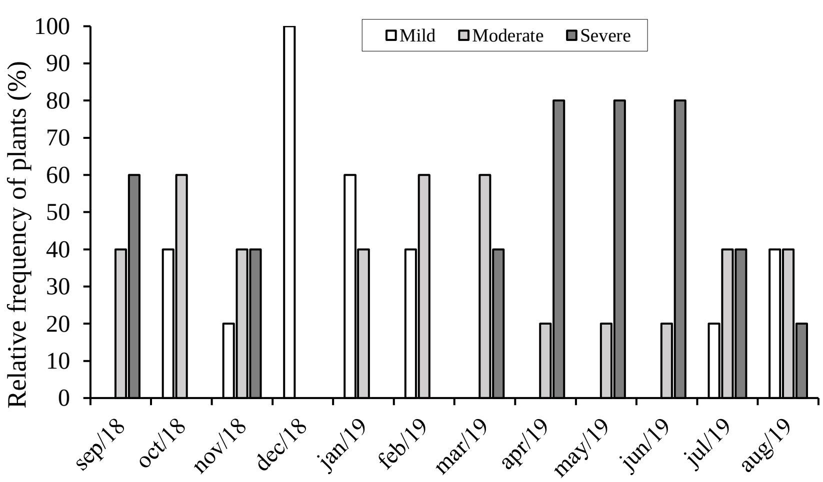

Figure 2. Relative frequency of different intensities of choking symptoms.

On the other hand, there was a significant impact of seasonal variations on growth plants. The leaf emission in n spring (September to December) was 2.45±0.18 leaves month^{-1}, in summer (December to March), 3.39 ±0.88, in autumn (March to June), 2.3 ±0.54 and in winter (June to August), 1.36 ±0.19 (Figure 3F). The plants height (Figures 3A and 3B), stalk length (Figure 3C) and leaves number at flowering (Figure 3D), in general, exhibited higher average values from November 2018 to April 2019, while the hand number was higher from December 2018 to April 2019 (Figure 3E).

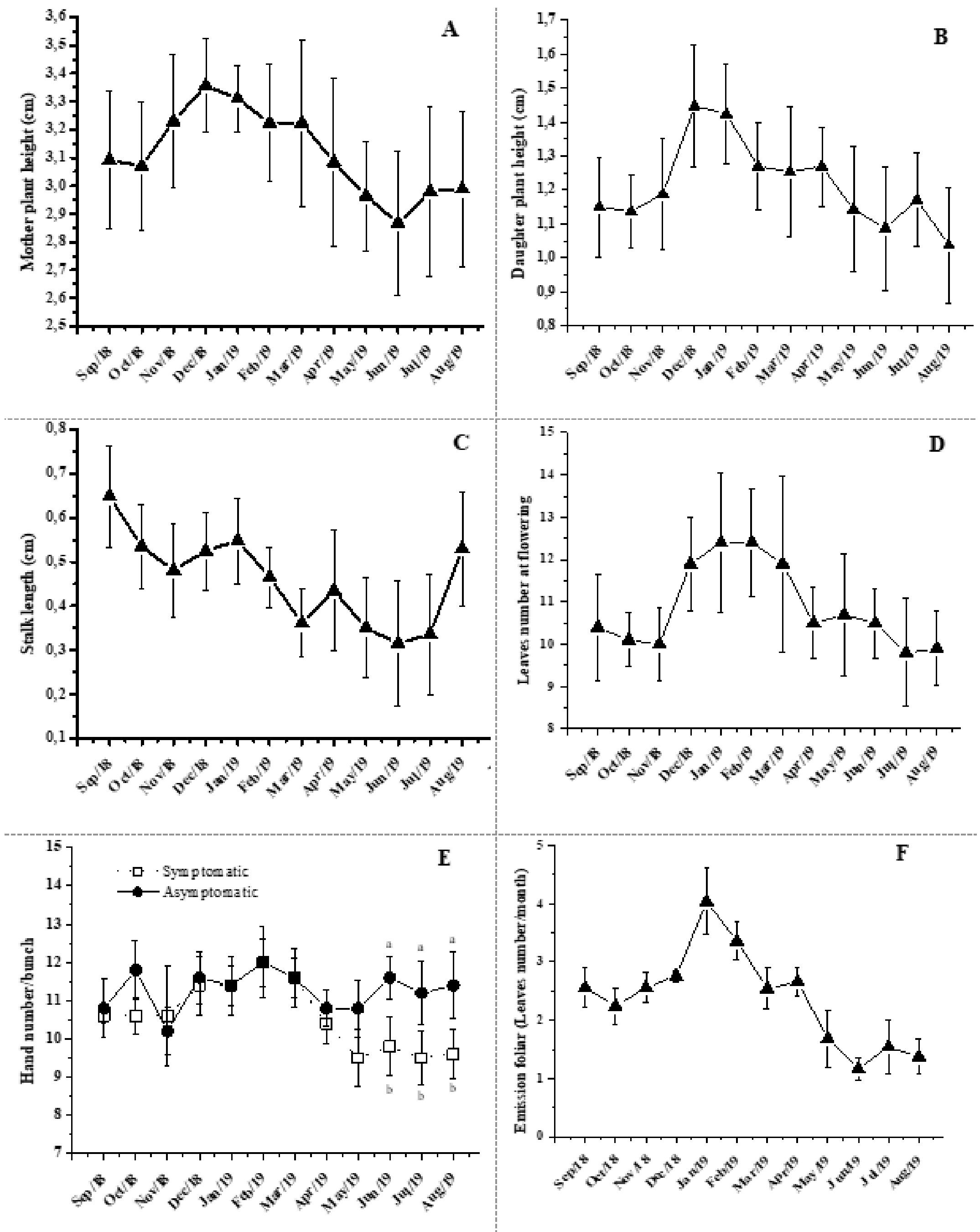

Figure 3. Morphological characteristics of plants with and without choking symptoms. Mean values obtained from ten replicates selected monthly for each treatment.

Climatic variations and choking

The availability of radiation was low in February/2018 in November 2019 (Figure 4A), due to the reduction of the photoperiod and increased nebulosity. There were 130 cloudy days, 124 partially cloudy days tending to cloudy, 74 days partially cloudy tending to open and only 37 days with open sky.

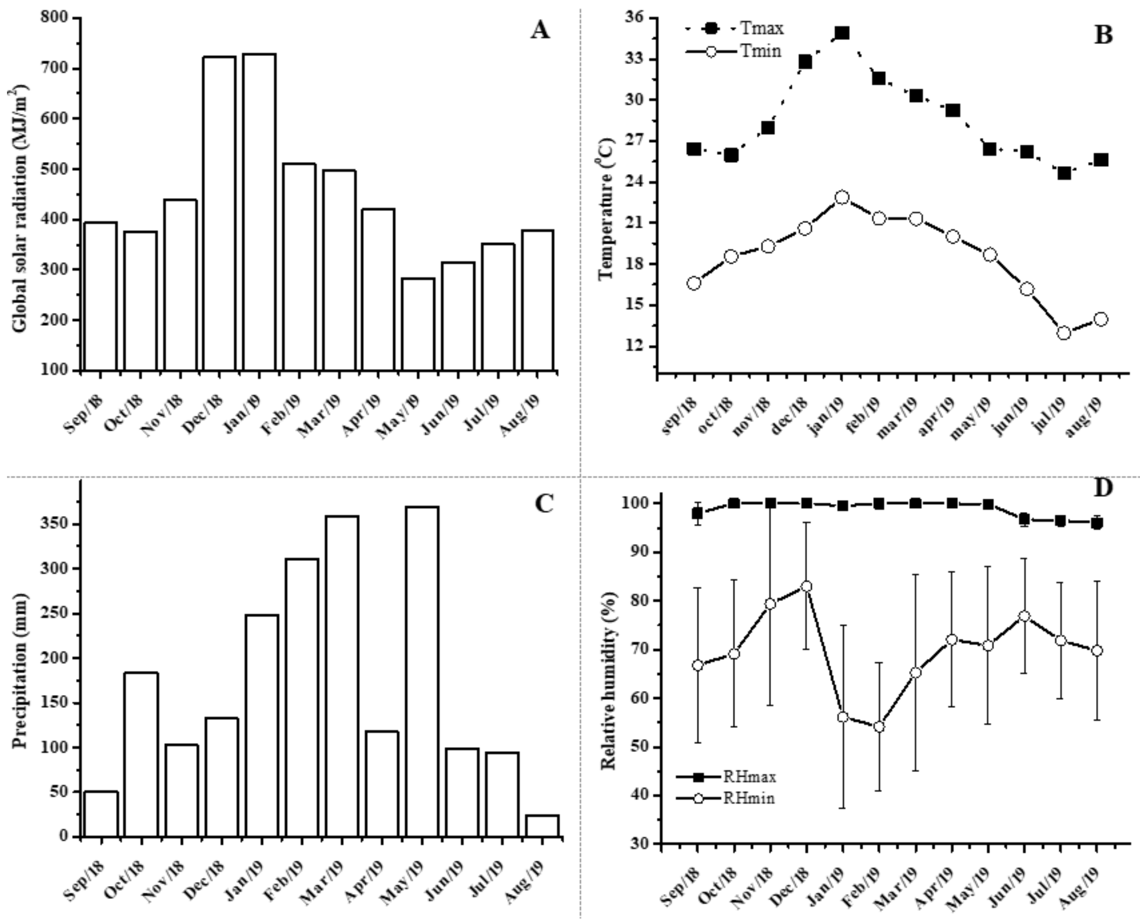

Figure 4. Climatic variables in the experimental period.

The limit temperatures for banana growth, which are 15 and 38 °C (Robinson and Saúco, 2011), were exceeded by the minimum limit in September 2018 and June to August 2019, due to many cold fronts (Figure 4B). Precipitatiom was 2090 mm year^{-1} (Figure 4C), poorly distributed. In September 2018 and August 2019, the volume of rain did not exceed the 100 mm month^{-1} indicated as adequate (Robinson and Saúco, 2011), while in January, February, March and May 2019 the rainfall was at least double necessary. Relative humidity (RH) is high in region because of its warm temperatures and surrounding bodies of water (Figure 4D). RHmax varied slightly, from 95.20 to 98.71, while RHmim, slightly more, from 50.68 to 76.29%, reaching values lower in January and February 2019, coinciding with Rad, Tmax and Tmin higher.

Choking can be associated mainly with low temperature (Figure 4B) combined with low availability of radiation (Figure 4A), but also with drought and excessive precipitation (Figure 4C). The reduction in the number of hands per bunch (Figure 3E), indicates a reduction in yield, is due to the decrease in the number of female flowers locules (Turner and Lahav, 1983) that occurred at least three months earlier (Robinson and Saúco, 2011). In this experiment, the twisted fruits and of the different sizes in the bunch occurred, respectively, in 21.67, 60.83 and 17.52% of plants symptomatics, respectively (Figure 2).

These changes are associated with the low temperature during the differentiation process that of fruit that induces disturbances in their morphogenesis (Turner, 1995). Changes in the positioning of the leaves, which become more vertical (shorter internodes) and the loss of spiral phyllotaxis, more horizontal cause a reduction in the production of photoassimilates and contribute to a reduction in fruit growths. The bunch abortion was only detected in April 2019 (1.66% of plants).

Nutritional status of plants and choking

Ten nutrients of the eleven analized were found to be below reference value, in at least one month. Mn was the element whose leaf content was always adequate. This suggests that nutritional deprivation can contribute to the occurrence of the ckoking. However, only P, Ca and Fe exhibited different levels between plants with symptoms and without symptoms ($p< 0.05$) (Figures 5 and 6). The N content in many months was below the reference value for flowering (Figure 5A). Despite the high P content in the soil, the plants showed lower levels than those reference values from October to January.

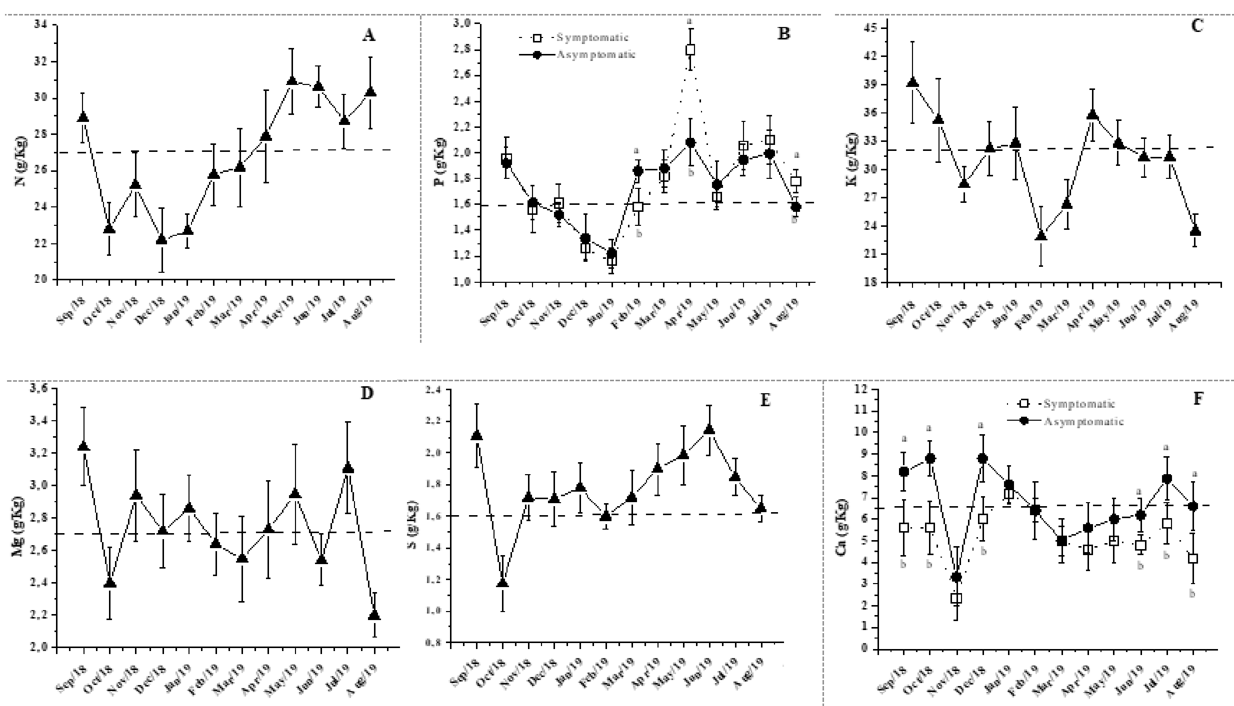

Figure 5. Macronutrient’s content (third leaf in fowering stage) in plants in plants with and without choking symptom.

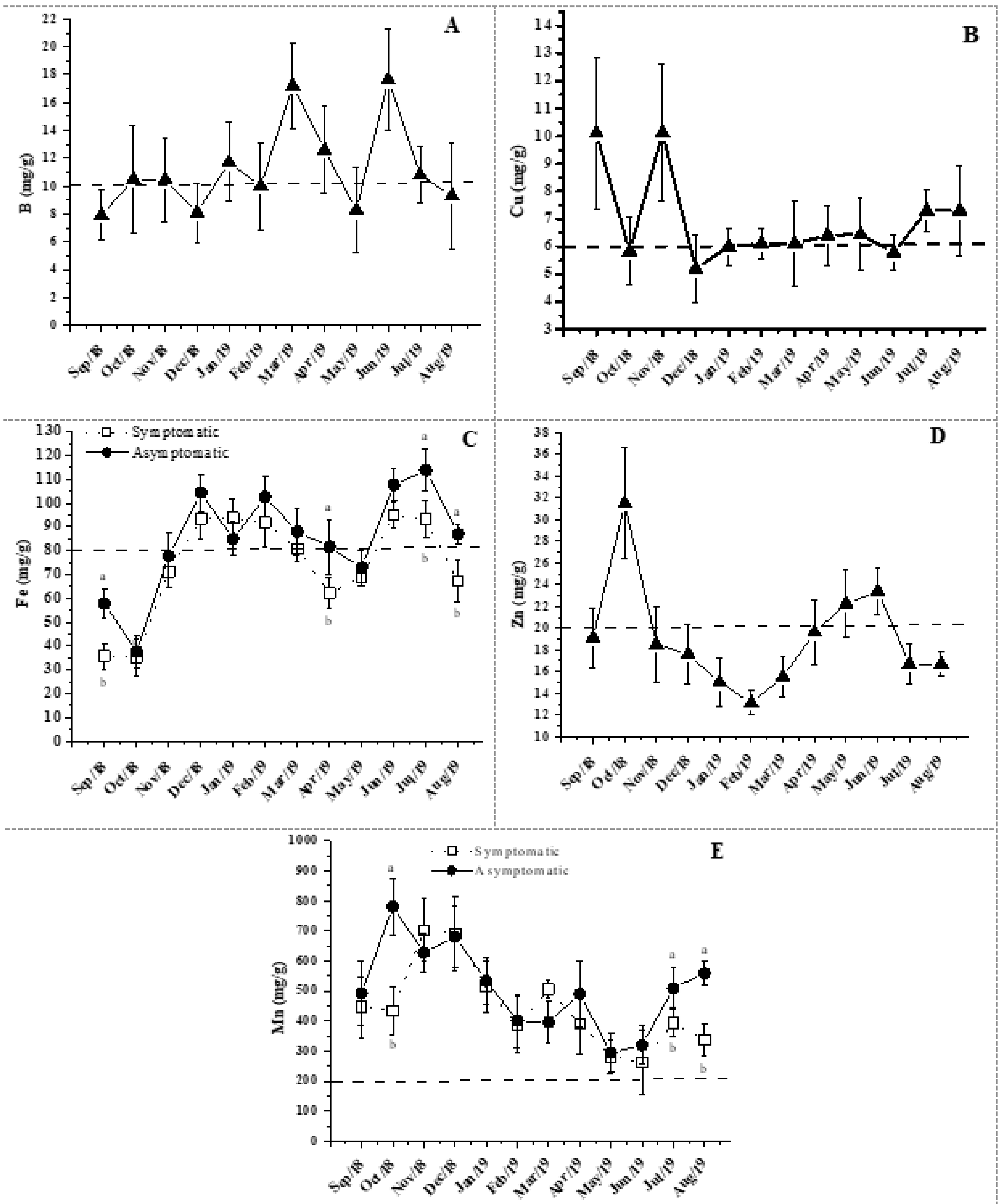

Figure 6. Macronutrient's content (third leaf in fowering stage) in plants in plants with and without choking symptom. The dashed line indicates the reference value for cultivar nanica. Mean values obtained from ten replicates. Means followed by different letter are significantly diferente by tukey's test (p< 0.05).

There were differences in the leaf P content between plants with and without symptoms, but with varied response, in February plants with symptoms showed a lower content, while in April and August, it was bigg (Figure 5B). In September 2018, with the beginning of spring (Figure 4), favorable climatic conditions stimulate growth and the demand for nutrients in the drains, which justifies the lower contents of some nutrients in the leaf tissue, unlike March to August 2019 (autumn and winter) (Figures 5 and 6). The dashed line indicates the reference value for cultivar Nanica. Mean values obtained from ten replicates Means followed by different letter, are significantly diferente by Tukey's test (p< 0.05).

Despite the deficiency of K, as well as N, deficiency, they can induce choking (Robinson and Sáuco, 2011), there was no difference in the K content between asymptomatic and symptomatic plants, which was below the reference value in November 2018, February 2018, March 2018 and August 2019 (Figure 5C), months with less severe symptoms of choking (Figure 2). The Mg content was significantly below the reference value in October and August 2018 (Figure 5D), while of S, only in October 2018 (Figure 5E), due to the change from the season for spring. Therefore, K, Mg and S do not seem related to choking.

Ca exhibited contents below the reference value in six months evaluated, with differences in levels between symptomatic and asymptomatic plants ($p< 0.05$) (Figure 5F). This agrees with the fact that 35.27% plants with choking exhibited symptoms of Ca deficiency in young leaves, such as chlorosis in leaf margin, thickening of the nerve and reduction in the leaf area (Freitas *et al.*, 2015). Meristematic regions require large amounts of Ca due to the formation of the cell wall (Marschner, 2012) at the same time they have few stomata.

In plants that have autonomous flowering, such as banana plant, Ca is the secondary messenger in response to gibberelin (GA) that results in stem elongation and floral emission. In this sense, the Ca content was associated to GA in plantain (Hernández *et al.*, 2012). However, the length of the stalk did not vary between choked and non-choked plants ($p< 0.05$) (Figure 3). The low Ca contents from March to August are the consequence of autumn and winter (Figures 4 and 5). Because it is not very mobile, Ca distribution depends a lot on transpiration (Torres and Castillo, 2013). High humidity, low temperature and low transpiration rate may reduce Ca uptake and translocation, resulting in deficiency (Kumar *et al*., 2015). Low radiation also reduces Ca concentration in xylem sap (Montanaro *et al.*, 2006).

B exhibited content below the reference value in September and December 2018, May and August 2019 (Figure 6A), while Cu only in December 2018 (Figure 6B). Fe content was higher in plants without symptoms in September 2018, April, July and August 2019 (Figure 6C). There were no differences in leaf Zn levels between plants with and without symptoms of choking ($p< 0.05$) (Figure 6D). Although no leaf deficiency symptoms were observed, Zn had lower average levels than the reference value in 9 months; therefore, it was the most critical nutrient, with a declining trend from October/2018 to February 2019 due greater plant growth (Figure 3). According to Mattiello *et al.* (2015), the visual symptoms of Zn deficiency normally occur when plants are suffering severe stress.

The relationship between Zn and choking is decorrent of your essenciability for the synthesis of tryptophan, which is a precursor in one of the auxins (IAA) synthesis pathways (Torres and Castillo, 2013). The main site of AIA synthesis is the apical meristem, so Zn must reach this point local in the plant. Zn is also directly involved in biosynthesis of gibberellins (GA) (Sekimoto *et al.*, 1997). Concomitantly, IAA exert strong effect on bioactive GA levels (Ross *et al.*, 2018). This agrees with loss of spiral phyllotaxis, shortening of internodes and with the difficulty in curvature of the stalk in its protrusion with the bunch, as well high incidence of abnormal fruits. Zn is involved in metabolism of nucleic acids, carbohydrates and protein (Marschner, 2012), another way to affect plant and fruit growth.

When evaluating plants with Zn levels below the reference value, no differences were found in the frequency of plants with and without symptoms of choking in 5 months (Figure 7A). This may be related to the fact that plants without symptoms demand more Zn because they have a higher growth rate or size. When the climatic condition was favorable to growth, such as January at March 2019, all the plants evaluated had Zn contents below the reference value (Figure 7A). In this period, Tmax was high, the RHmin showed lower minimum values and precipitation was abundant, favoring the transpiration and translocation of nutrients in the xylem.

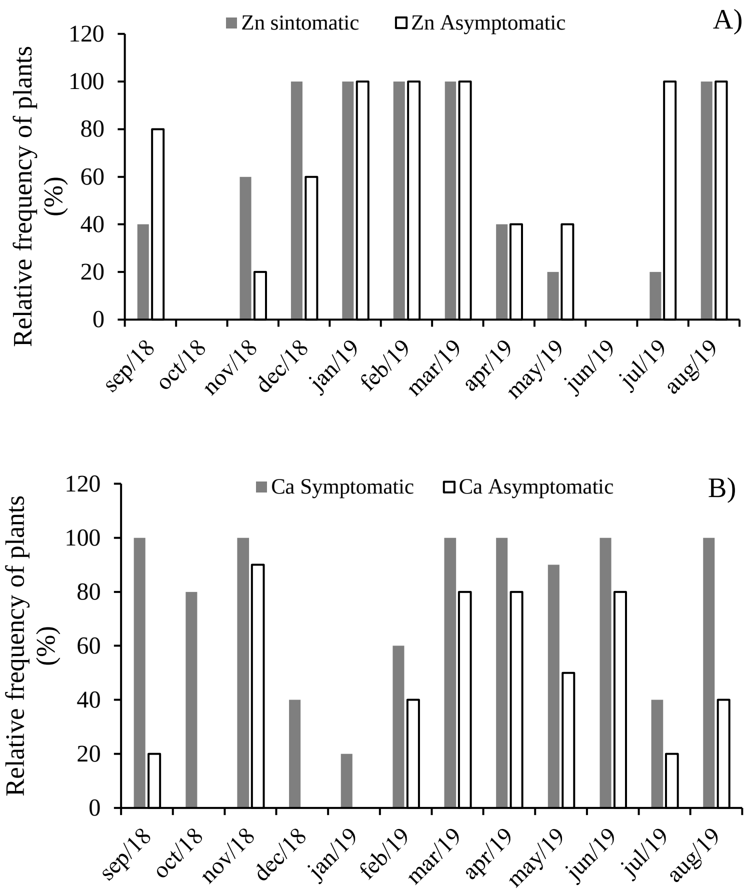

Figure 7. Relative frequency of plants choked with leaf contents below the reference value of Zn (A) and Ca (B).

This reinforces the hypothesis that Zn deficiency was more related to the limited supply than to the adverse climatic condition. Zn usability by plants decreases by high levels o f P in the soil (Mousavi *et al*., 2013), condition that occurred in this study. However, Zn deficiency increases in cold and wet weather conditions (Mousavi *et al*., 2013) and soil saturated with water (Hafeez *et al*., 2013). Application of large amounts of phosphate and organic matter to the soil can induce the formation of stable complexes between Ca and P in the soil, also changing the availability of Ca (Robinson and Sharple, 1996).

The frequency of choked plants with Ca levels below the reference value was higher than in asymptomatic plants (Figure 7B), indicating a relationship between the deficiency and the physiological disorder. In subtropical regions, with climatic conditions close to the region of this study, Ca deficiency in banana is reported because of an intense growth flow in summer or spring (Robinson and Saúco, 2011). However, the lowest contents of Ca occurred in periods of lower growth (Figure 5). Antagonistic interactions with K, Mg and Mn also affect the Ca content (Robinson and Saúco, 2011; Marschner, 2012). Although Mn was abundant in the leaf tissue throughout the experimental period, it was lower in choked plants (Figure 6).

Application of large amounts of phosphate along with organic matter to the soil can change also the availability of Ca (Robinson and Sharple, 1996), what may have occurred in the experimental area. In banana hybrid 'FHIA-18', there was a quadratic response of Ca and Zn content foliar with diferentes levels of phosphate fertilization (Bolfarini *et al.*, 2020).

Changes in cellular Ca^{+2} level, which functions as a messenger in modulating diverse processes that are important for stress adaptation (drought, cold, heat, flooding, salt and wind) (Reddy *et al.*, 2011). It was considered an important biomarker in response and adaption to cold environments em banana Grand Naine and Williams cultivars (El-Mahdy *et al*., 2018). The plant's responses to cold may have been impaired since the lower Tmin (Figure 4B) occurred concomitantly with lower leaf Ca contents, especially in choked plants (Figure 5).

The average leaf P content in April 2019 was very high in choked plants, but there are no subsidies to suggest the excess of P. Marschner (2012) mentions that the excess of P in the plant can impose a physiological deficiency of Zn, due to the lower availability of soluble Zn. Ca and Zn participate of growth and response mechanisms to stress. Plants deficient in Zn, because they have lower endogenous levels of IAA, are likely to have a limited response to different types of abiotic stresses (Raja *et al*., 2017), some mediated by Ca (Reddy *et al*., 2011). At the same time, plants deficient in Ca will have change in Ca^{+2} homeostasis processe that can impact on IAA uptake and consequently its action (Reddy *et al*., 2011).

Plants deficient in Ca and Zn will also fail to protect cellular components from oxidation by overproduction of reactive oxygen species (ROS), due to the change in the signaling cascade ROS-Ca^{+2} (Savvides *et al*., 2016) and lower synthesis of Cu/Zn-superoxide dismutase (SOD) (Mattiello *et al*., 2015). Zn is also part different zinc-finger proteins which contribute significantly towards protection against a variety of environmental stresses (Raja *et al*., 2017), expressed in *Musa* sp. (Sreedharan *et al*., 2012).

Conclusions

For the experimental conditions evaluated, choking does not affect plant growth, only the number of hands per bunch and fruits quality. It occurred throughout the year, with a predominance of severe symptoms of April at June due a redução da temperatura e radiation. The physiological disorder was related to Ca and Zn deficiencys.

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