NITROGEN, PHOSPHORUS AND POTASSIUM CONTENT IN DIFFERENT ORGANS OF PINEAPPLE CULTIVARS AT DIFFERENT PLANTING DENSITY †

[CONTENIDO DE NITRÓGENO, FÓSFORO Y POTASIO EN DIFERENTES ÓRGANOS DE CULTIVARES DE PIÑA A DIFERENTES DENSIDADES DE PLANTACIÓN]

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SUMMARY

Background. The amount of nutrients required by pineapple varies depending on the cultivar and planting density. Knowing the nutrient requirement in quantity and the appropriate phenological stage will allow the development of an adequate fertilization program. **Objective.** To determine the effect of pineapple cultivar and planting density on N, P, and K content during plant development and at harvest. **Methodology.** The cultivars 'Smooth Cayenne', 'Champaka', and 'MD-2' were established at 30000, 45000, and 60000 plants ha^{-1}. Eight samples were taken to determine the N, P, and K content in the organs and the total plant. **Results.** The highest and lowest N, P, and K contents were detected in the leaf and root, respectively. The highest N and K contents occurred at 441 - 506 days after planting. Higher P content occurred close to harvest. The highest N, P, and K contents per plant were at 30000 plants ha^{-1} (14.86, 1.52, and 16.29 g plant^{-1}, respectively) and the lowest at 60000 plants ha^{-1} (10.16, 1.13, and 14.6 g plant^{-1}, respectively). Higher N, P, and K contents per hectare were detected with 60000 plants ha^{-1} (609, 68, and 875 kg ha^{-1}, respectively). At harvest, 'Smooth Cayenne' at 60000 plants ha^{-1} accumulated the highest amount of N, P, and K (147, 37, and 306 kg ha^{-1}, respectively). **Implications.** The changes that can occur in the nutrient requirements of pineapple as a function of cultivar, planting density, and stage of plant development were identified. This information will be useful for producers, agricultural technicians, and researchers in Mexico and the world, to generate fertilization programs or establish new research. **Conclusion.** At the beginning of plant growth, a higher N, P, and K contents in the leaf, this amount decreases as the fruit harvest approaches. Regardless of cultivar, the highest nutrient content per plant occurs at the lowest planting density, however, the highest content per hectare occurs at the highest planting density. At harvest time, fewer nutrients are removed from the soil with 'Champaka' and 'MD-2' fruit.
Key words: *Ananas comosus* L.; Plant growth; Nutrient uptake; Soil fertility; Fertilization.

RESUMEN

Antecedentes. La cantidad de nutrientes requeridos por la piña cambia en función del cultivar y la densidad de plantación. Conocer el requerimiento nutrimental en cantidad y etapa fenológica oportuna, permitirá desarrollar un adecuado programa de fertilización. **Objetivo.** Determinar el efecto del cultivar y la densidad de plantación en el contenido de N, P y K durante el desarrollo de la planta y la cosecha de la piña. **Metodología.** Los cultivares 'Cayena Lisa', 'Champaka' y 'MD-2' se establecieron a 30000, 45000 y 60000 plantas ha^{-1}. Ocho muestreos fueron realizados

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para determinar el contenido de N, P y K en los órganos y la planta total. **Resultados.** Los mayores y menores contenidos de N, P y K se detectaron en la hoja y raíz, respectivamente. Los mayores contenidos de N y K ocurrieron a los 441 - 506 días después de la plantación. El mayor contenido de P ocurrió próximo a cosecha. Los mayores contenidos de N, P y K por planta fueron con 30000 plantas ha^{-1} (14.86, 1.52 y 16.29 g $planta^{-1}$, respectivamente) y los menores con 60000 plantas ha^{-1} (10.16, 1.13 y 14.6 g $planta^{-1}$, respectivamente). El mayor contenido de N, P y K por hectárea se detectó con 60000 plantas ha^{-1} (609, 68 y 875 kg ha^{-1}, respectivamente). En la cosecha, 'Cayena Lisa' a 60000 plantas ha^{-1} presentó el mayor contenido de N, P y K (147, 37 y 306 kg ha^{-1}, respectivamente). **Implicaciones.** Se identificó los cambios que pueden ocurrir en el requerimiento nutrimental de la piña en función del cultivar, densidad de plantación y etapa fenológica de la planta. Esta información será útil para productores, técnicos agrícolas e investigadores de México y del mundo, para generar programas de fertilización o para nuevas investigaciones. **Conclusión.** Al inicio del crecimiento de la planta, un mayor contenido de N, P y K se presenta en la hoja, este contenido disminuye a medida que se acerca la cosecha de fruto. Independiente del cultivar, el mayor contenido de nutrientes ocurre con la menor densidad de plantación, sin embargo, el mayor contenido por hectarea ocurre con la densidad de plantación más alta. Al momento de la cosecha, una menor cantidad de nutrientes se retira del suelo con los frutos de ‘Champaka’ y ‘MD-2’.

Palabras claves: *Ananas comosus* L.; Crecimiento de planta; Absorción de nutrientes; Fertilidad de suelo; Fertilización.

INTRODUCTION

The nitrogen (N), phosphorous (P) and potassium (K) are nutrients required by the pineapple along its production cycle. K is reported as the nutrient extracted in greater amount, it is associated with weight gain and improve fruit quality. N is the second nutrient more required by the plant, it is associated with the amino acid synthesis and protein formation; it had a positive influence in plant development, yield, and fruit quality. P is between the third and the fourth nutrient more required, it participates in energy transfer as part of the ATP, it is a component of nucleic acids, nucleotides, coenzymes, phospholipids and phytic acid (Maia *et al*., 2020). Besides as the plant growths, the nutritional status of the plant change and those changes can be perceived in the concentration and accumulation of nutrients in different parts of the plant (Ahmed *et al*., 2007).

The cultivar used influences plant size, nutrient absorption, dry matter production, fruit yield and dry matter accumulation in the different organs of the plant (Hanafi *et al*., 2009; Neri *et al*., 2021); which affects the concentration and accumulation of nutrients in each part of the plant (Sampaio *et al*., 2011; Trejo *et al*., 2020). Planting density is another factor that can affect the concentration of nutrients because it modifies the size of the plant; as the plantation density increases, the number of leaves emitted, the size of the stem and the size of the fruit are reduced (Cardoso *et al*., 2013; Souza *et al*., 2019). Although a smaller size and amount of dry matter is obtained from the plant in the highest planting density, the yield, and the amount of dry matter per hectare is greater as the planting density increases, consequently, the amount of nutrient extracted per hectare increases as the amount of dry matter produced increases (Souza *et al*., 2019).

The fruit and the crown are removed from the field during harvest, which means that with its biomass, 55-78% of the N and 39-60% of the total P absorbed by the plant can be removed from the production system (Ahmed *et al*., 2007; Salgado García *et al*., 2017). After the harvest, the residues that remain in the field: root, leaf, stem, and peduncle; can represent 64-86% of the total biomass produced (Hanafi *et al*., 2009). This biomass represents a source of organic matter and nutrients that can be used in a second production cycle or in the subsequent crop.

In Mexico, before the year 2000, low planting densities (< 30000 plants ha^{-1}) were used on commercial farms. Considering the above, an experiment was established to evaluate three planting densities in three pineapple cultivars. The first two cultivars were 'Smooth Cayenne' and 'MD-2', in 2021, these varieties represented 67% and 29% of the total area planted in Mexico (SIAP, 2023). The third cultivar was 'Champaka', a promising genotype for new commercial plantations (Uriza-Ávila *et al*., 2018). The results showed the effect of planting density and cultivar on plant growth, yield, and fruit quality (Rebolledo-Martínez *et al*., 2005; Rebolledo Martínez *et al.*, 2006), however, it is unknown how these factors affect the behavior of nutrients during plant development. For this reason, the objective was to determine the effect of planting density and cultivar on the N, P and K content during plant development, as well as the amount accumulated in the fruit at harvest time. This information will be useful to agricultural technicians and pineapple producers around the world, as well as to agricultural researchers, to generate fertilization programs or to establish new experimental works.

MATERIALS AND METHODS

An experiment was stablished in the Papaloapan Basin, within the facilities of the ‘Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias’ (INIFAP). The ‘Papaloapan’ Experimental Station (INIFAP) is located in a region with an Aw_0 climate and it is characterized by having dystric cambisol soils, poor in organic matter and nutrients: 4.8 pH; 0.043 dS m^{-1} EC; 0.92 and 0.053 % of organic matter and N, respectively; 3 mg kg^{-1} P; 0.6 and 0.74 meq 100 g^{-1} of K and Ca, respectively; 0.08 $_{c}$mol kg^{-1} Mg; 0.34, 50, 1.23, 0.90 and 16 mg kg^{-1} of Na, Fe, Cu, Zn and Mn, respectively.

Pineapple shoots 'MD-2', 'Smooth Cayenne' and 'Champaka' weighing 400 to 500 g were selected from the gene bank of 'Papaloapan' Experimental Station. A split plots treatment arrangement with a randomized block design and four repetitions was used. Planting density (30000, 45000 and 60000 plants ha^{-1}) was considerate as a large plot and the small plot was the pineapple cultivar. The experimental unit was 120 plants. The experimental unit consisted of three 9 m long planting beds (distance of 1.25 m from center to center of the beds) with two rows per bed spaced 45cm.

The field experiment was carried out without an irrigation application. Soil moisture depended only on rainfall. The planting was done in December. The fertilization rate changed according to planting density. For 60000 plant ha^{-1} 12-8-12-4 was applied, for 45000 plant ha^{-1} the dose was 14-8-14-4 and for 30000 plant ha^{-1} the dose was 17-8-17-4 g $plant^{-1}$ of N-P_2O_5-K_2O-Mg, respectively. For the three planting densities, 75% of the fertilizer dose was applied solidly, divided into three applications, at 229, 278 and 407 days after planting (DAP). The fertilizers used were urea (46% N), potassium sulfate (50% K_2O), potassium chloride (60% K_2O), diammonium phosphate (18-46% of N and P_2O_5) and magnesium sulfate (16% MgO). The remaining 25% of the dose was applied in liquid form, divided into five applications (at 464, 508, 537, 623 and 661 DAP). For each 200 L of water, 3, 3, 2 and 1 kg of urea, potassium chloride, diammonium phosphate and magnesium sulfate were applied, respectively. Each plant received 70 ml of the solution. Micronutrients were applied in liquid form, for 60000 plants ha^{-1} 3.0-2.8-2.18-1.2-2.4 was applied, for 45000 plants ha^{-1} 2.2-2.1-1.6-0.9-1.8 was applied and for 30000 plants ha^{-1} 1.5-1.4-1.1-0.6-1.2 kg ha^{-1} of Fe, Zn, B, Mn and Cu, respectively, were applied. Weed control and pest control (symphylids, Mealybugs and nematodes) were carried out based on the recommendations of Rebolledo *et al*. (1998) using the recommended agrochemicals.

The flower induction treatment was carried out with calcium carbide dissolved in water at 2%. Three applications were made, at 704, 707 and 710 DAP. At each date, 60 ml of the solution was applied to each plant. The application was made between 18:00 and 22:00 hours.

Eight plant samplings were made during the entire production cycle. On each sampling date, one fully competent plant was obtained from each experimental unit. Sampling was carried out at 108, 153, 202, 278, 321, 442, 506 and 551 DAP, which were segmented into roots, stems, leaves (Only green leaves), peduncles, and fruits. The total fresh weight of each plant organ was recorded. Representative samples were obtained from each organ and dried in a forced air oven at 70 °C until constant weight was reached. Dry matter was determined for each sample by gravimetry. The dry matter was subjected to analysis to determine the nitrogen concentration, with the micro Kjeldahl method (Bremner, 1965); phosphorus, with the colorimetric method of Olsen *et al*. (1954); and potassium, by atomic emission spectroscopy (Chapman, 1973).

On each sampling date, the content of nutrients (Cn) in each plant organ was determined using the equation $Cn = nutrient\ concentration \times dry\ matter\ weight$.

Likewise, the nutrient content per plant (Cnp) was calculated using the equation $C_{np} = C_{roots} + C_{stem} + C_{leaves} + C_{peduncle} + C_{fruit}$ (Maia *et al*., 2016).

The fruits were harvested at 551 DAP, when the fruits presented an external ripening of 50% (Soler, 1990). To estimate yield, the fresh weight of 25 plants for 'MD-2' (2.1, 1.9 and 1.8 kg $plant^{-1}$ for 30000, 45000 and 60000 plants ha^{-1}, respectively), 'Smooth cayenne' (2.7, 2.5 and 2.3 kg $plant^{-1}$ for 30000, 45000 and 60000 plants ha^{-1}, respectively) and 'Champaka' (2.5, 2.4 and 2.2 kg $plant^{-1}$ for 30000, 45000 and 60000 plants ha^{-1}, respectively) cultivars was recorded for each experimental unit. Yield, fresh and dry matter results are not discussed in this manuscript.

The content of N, P and K in each organ and in the plant by sampling date are represented with the arithmetic mean and standard deviation. The influence of planting density and cultivar on nutrient content was determined with mixed models. These models considered each factor independently and the interaction between them. A null model was also included, under the assumption that none of the factors was a good predictor of nutrient content, with a total of five models used for each organ. The best model was selected considering the lowest value of the Akaike Information Criterion (AIC), which is a measure of the relative quality of a statistical model for a data set, which manages a trade-off between the goodness of fit and the complexity of the model (Vrieze, 2012). A posthoc test (Tukey with $p<0.05$) was performed on the selected model to identify differences between the levels of the fixed effects.

RESULTS

Nutrient content during plant growth

Of the total N content by the plant, independent of the planting density, cultivar, and phenological stage, the leaf is the one that accumulated the greatest amount, while the least amount is accumulated by the root (Figure 1). At densities of 30000 and 45000 plants ha^{-1}, in the three cultivars, the highest N content in the plant occurred at 441 DAP (Figure 1 A, B, C, D, E, F). At a density of 60000 plants ha^{-1}, the highest N content in 'Champaka' and 'Smooth Cayenne' was detected between 441 and 551 DAP (Figure 1 G, I).

The leaf was the organ with the highest P content until before harvest (506 DAP), in the three planting densities and in the three cultivars (Figure 2). In all planting densities, the highest P content in 'Champaka' and 'Smooth Cayenne' was detected at 551 DAP (Figure 2 A, C, D, F, G, I), while for 'MD-2' the moment changed depending on the planting density (Figure 2 B, E, H).

In the three planting densities, until before 551 DAP, the highest K content was detected in the leaf (Figure 3). In all of them, the highest K content in 'MD-2' occurred at 441 DAP (Figure 3 B, E, H). The situation was different with 'Champaka' and 'Smooth Cayenne', where the highest K content changed as a function of planting density (Figure 3 A, C, D, F, G, I).

Nutrient content during fruit harvest

The N, P and K content in the different organs of the plant, in some cases, depending on the planting density, the cultivar or the interaction of both factors (Table 1). The N and K content in the stem, as well as the P content in the stem and leaf, are because of planting density. The N, P and K content in the peduncle depends on the cultivar. The N and K content in the leaf, as well as the P and K content in the fruit, are explained by the effect of planting density + cultivar + planting density:cultivar (Table 1).

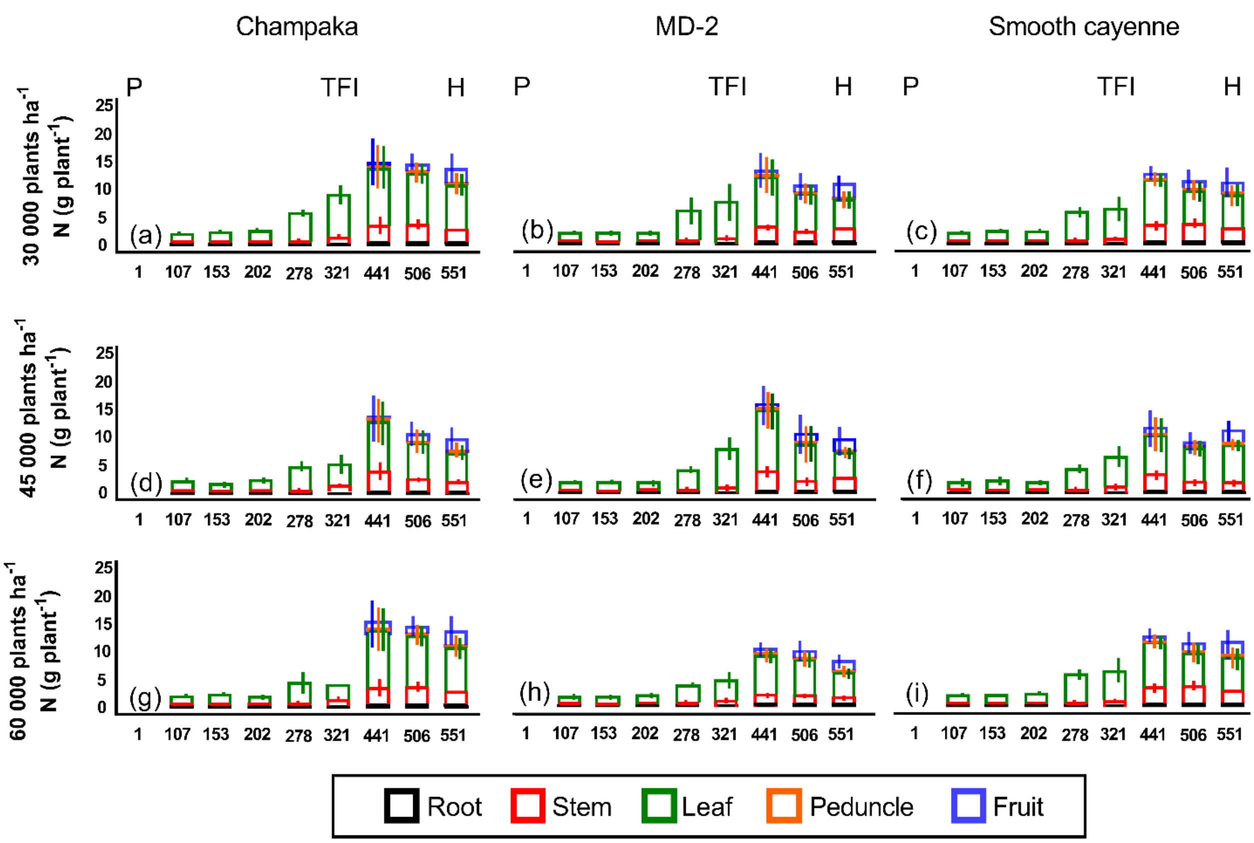

Figure 1. Nitrogen (N) content in different organs of the pineapple plant of the cultivars ‘Champaka’, ‘MD-2’ and ‘Smooth Cayenne’, established at 30000 (A, B, C), 45000 (D, E, F) and 60000 (G, H, I) plants per hectare, in samples taken on different days after planting. P = planting. TFI = Treatment for flowering induction. H = harvest.

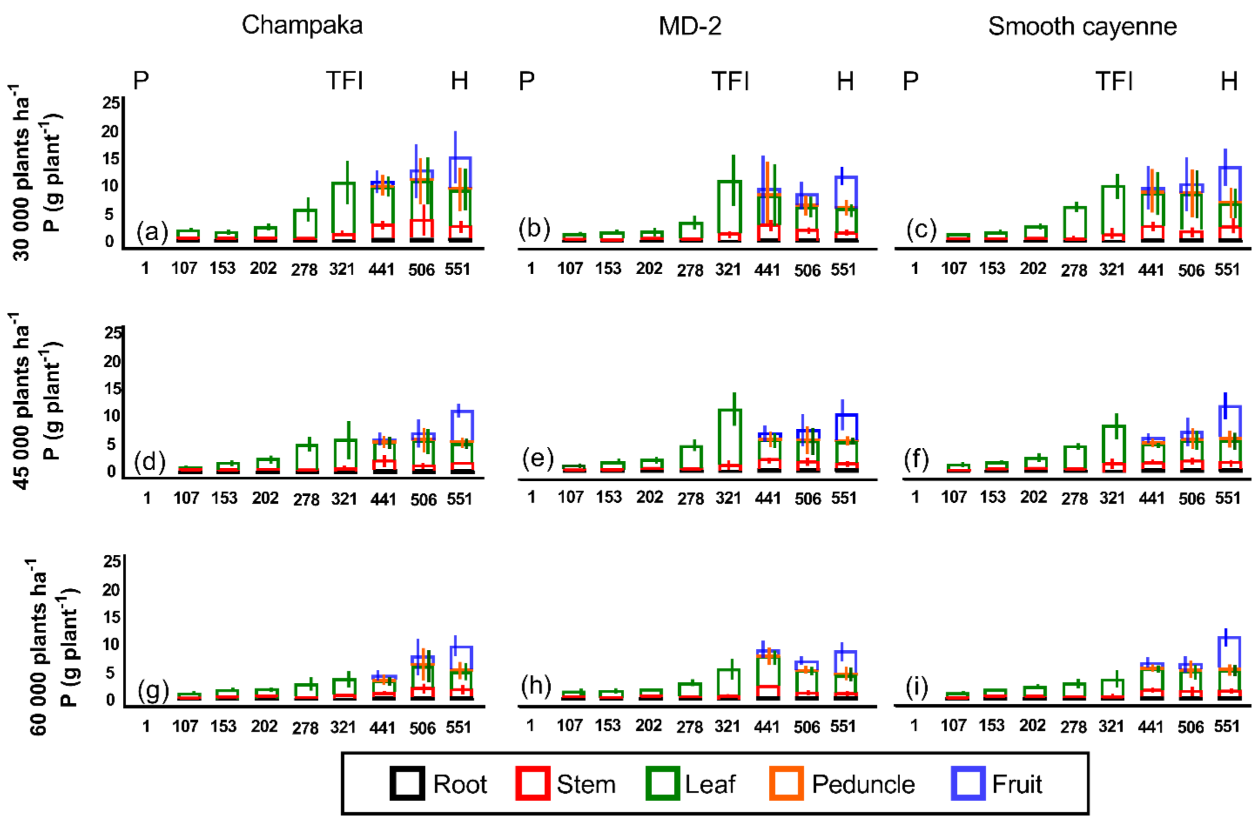

Figure 2. Phosphorous (P) content in different organs of the pineapple plant of the cultivars 'Champaka', 'MD-2' and 'Smooth Cayenne', established at 30,000 (A, B, C), 45,000 (D, E, F) and 60,000 (G, H, I) plants per hectare, in samples taken on different days after planting. P = planting. TFI = Treatment for flowering induction. H = harvest.

The density of 30000 plants ha^{-1} stimulated the highest N content in the stem compared to the density of 60000 plants ha^{-1}. The N content in the peduncle was similar in the three pineapple cultivars. The N content in the leaves was higher with 'Champaka' at the density of 30000 plants ha^{-1} compared to 'MD-2' at the densities of 30000 and 45000 plants ha^{-1} (Table 2).

A similar P content in the stem was detected in the three planting densities. The P content in the leaf was greater on plants established at 30000 plants ha^{-1} compared to those established at 60000 plants ha^{-1}. The peduncle of 'MD-2' presented a higher P content compared to 'Champaka' and 'Smooth Cayenne'. In the fruit, the P content by 'Smooth Cayenne' at the density of 30000 plants ha^{-1} was higher compared to 'MD-2' at the density of 60000 plants ha^{-1} (Table 3).

The amount of K content by the stem was similar in the three planting densities. The K content by the peduncle was higher with 'MD-2' than with 'Champaka' and 'Smooth Cayenne'. The highest K content in leaves of 'Champaka' at 30000 plants ha^{-1} was higher than that of 'Champaka' at 45000 and 60000 plants ha^{-1}, 'MD-2' (60000 plants ha^{-1}) and 'Smooth Cayenne' (60000 plants ha^{-1}). The fruit of 'MD-2' established at 60000 plants ha^{-1} accumulated less amount of K compared to 'Champaka' established at 30000 plants ha^{-1} and 'Smooth Cayenne' established at the three planting densities (Table 4).

DISCUSSION

Previous reports indicate that nutrient content changes as a function of the cultivar (Hanafi *et al*., 2009), plant organ (Pegoraro *et al*., 2014b) or planting density (Souza *et al*., 2019). This situation was corroborated in the peduncle and stem, since, the N, P and K content depended on the cultivar, while the stem depended on the planting density. However, none of the factors considered in this study were able to explain the behavior of N, P and K content in the root, indicating that other factors are involved in the accumulation of nutrients in this organ. The N, P and K content in leaf and fruit is not attributed to a single factor but is influenced by the interaction of planting density and cultivar, therefore, it is speculated that the factors that affect the accumulation of nutrients in the leaf will also affect the accumulation of nutrients in the fruit. Nutrient content depends on the amount of biomass produced, increased leaf biomass promotes increased plant biomass (Hanafi *et al*., 2009; Mota *et al*., 2016), which is reflected in larger fruits (Teixeira *et al*., 2011; Vilela *et al*., 2015) and consequently with higher N, P

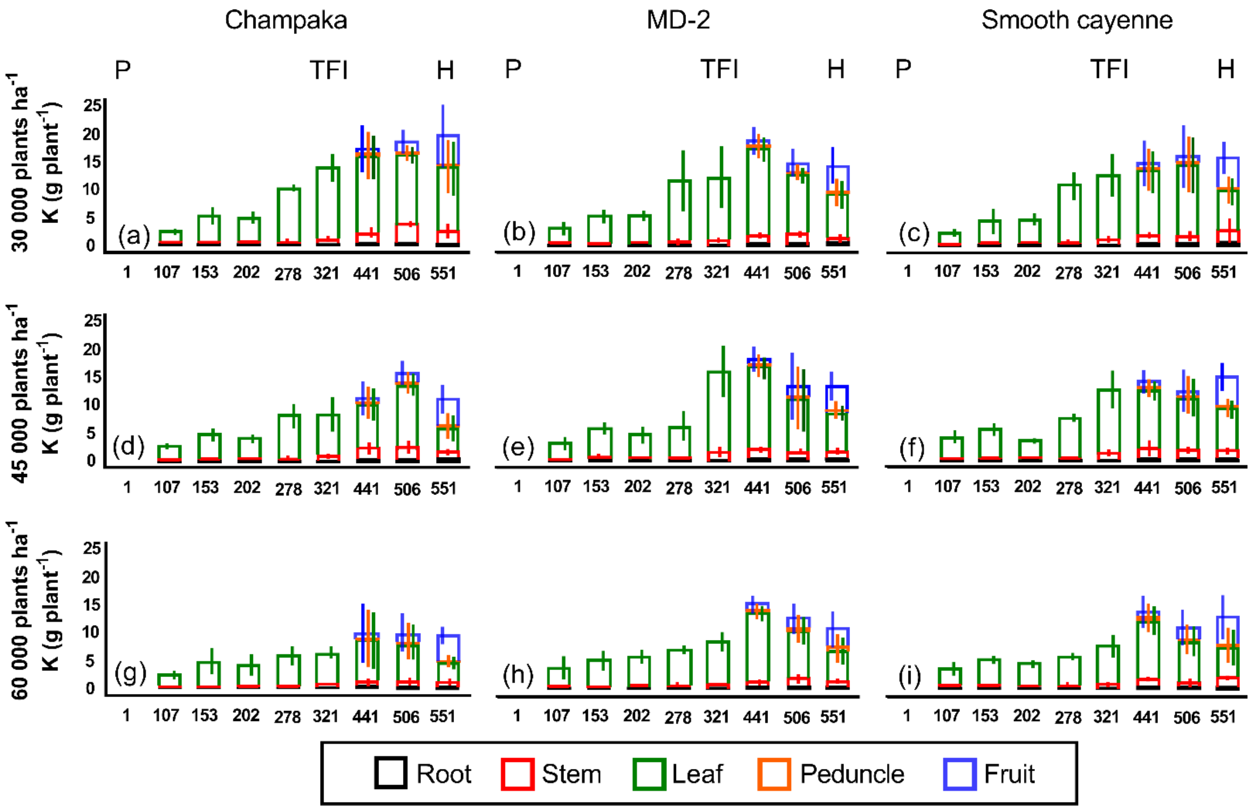

Figure 3. Potassium (K) content in different organs of the pineapple plant of the cultivars ‘Champaka’, ‘MD-2’ and ‘Smooth Cayenne’, established at 30000 (A, B, C), 45000 (D, E, F) and 60000 (G, H, I) plants per hectare, in samples taken on different days after planting. P = planting. TFI = Treatment for flowering induction. H = harvest.

and K content. In this study, the order of nutrient demand was little influenced by the cultivar and planting density, since the order of nutrient content in the three cultivars and in the three densities was: K>N>P, somewhat similar was observed with cv. ‘Vitória’ that, at different planting densities, the content order was K>N>P (Souza *et al*., 2019).

Changes in nutrient content as a function of plant organ is consistent with that reported by Pegoraro *et al*. (2014b). The greater accumulation of N, P and K in the leaf is attributed to the presence of chlorophyll molecules, enzymes, proteins, and nucleic acids that are required for different metabolic processes of the plant. Although the stem and the root are lignified organs, a greater N, P and K content in the stem compared to root, is attributed to the fact that the stem is a reserve organ for photoassimilates in the form of vascular parenchyma tissues and starch (d'Eeckenbrugge and Leal, 2018). On the other hand, the lower N, P and K content in the root is attributed to the fact that it is an absorption organ with lower N content, mainly constituted by fibrous tissues, rich in lignin and with a lower concentration of proteins (López-Herrera *et al*., 2014). It is very possible that during the development of the fruit a phenomenon of translocation of nutrients from the leaf and stem to the fruit has occurred, since the proportion of nutrients extracted by the leaf and stem increased compared to the first phenological stages of the crop.

No other studies were found to compare the behavior of N, P and K content throughout the pineapple growth cycle; therefore, these results will serve as a point of comparison for other studies. The results indicate that the maximum N, P and K content is achieved after TFI like those reported by Pegoraro *et al*. (2014b). In this case, the highest total N and K content occurred at the beginning of fruit development, while the highest total P content was detected at the final stage of fruit development, mainly in 'Champaka' and 'Smooth cayenne'. This can be related to the amount of dry matter produced or to the nutrient concentration in the plant tissue (Ávila-Escobedo *et al*., 2022). In the cv. 'Red Spanish', total dry matter accumulation and linear N content were reported as plant age increased (José *et al*., 2007). However, other research has shown that pineapple can reach its maximum dry matter accumulation at the time when fruit development begins and after this stage this value decreases (Malézieux, 1993; Zhang and Barthomew, 1997; Souza *et al*., 2007). That reduction can be attributed to

Table 1. Factors that influenced the behavior of nitrogen content in different organs of the pineapple plant, according to the best model of the Akaike information criterion (AIC)

Nutrient	Organ	Best model AIC
Nitrogen	Root	y ~ 1*
	Stem	y ~ Density
	Leaf	y ~ Density + Cultivar +Density:Cultivar
	Peduncle	y ~ Cultivar
	Fruit	y ~ 1*
Phosphorous	Root	y ~ 1*
	Stem	y ~ Density
	Leaf	y ~ Density
	Peduncle	y ~ Cultivar
	Fruit	y ~ Density + Cultivar +Density:Cultivar
Potassium	Root	y ~ 1*
	Stem	y ~ Density
	Leaf	y ~ Density + Cultivar +Density:Cultivar
	Peduncle	y ~ Cultivar
	Fruit	y ~ Density + Cultivar +Density:Cultivar

*The variability found cannot be explained by planting density or by Cultivar.

the loss of dry matter in the stem (Bartholomew, 2018) or by the disintegration of old leaves (Zhang and Barthomew, 1997; Pegoraro *et al*., 2014a), since, at the time of sampling only the green leaves present on the plant were considered. This explains the higher N and K content at the time when fruit development begins (441 DAP), since the highest accumulation of total dry matter in the plant was detected at this phenological stage in the three pineapple cultivars (Rebolledo-Martínez *et al*., 2005). Regarding P content, the highest values presented at the end of the fruit development stage (506 DAP) are attributed to the concentration of the nutrient in plant tissues and in the fruit. Previous studies indicate that the nutrient concentration in plant tissues can change depending on the phenological stage of pineapple, depending on the nutrient, the concentration can increase, decrease, or remain stable as plant age increases (Ramos *et al*., 2011). In this study, P concentration increased in the vegetative part, mainly with 'Champaka' and 'Smooth cayenne'. The average P concentration of these two cultivars in root, stem and leaf was 0.02, 0.12 and 0.07 mg kg^{-1} at 441 DAP, values that increased to 0.07, 0.14 and 0.09 mg kg^{-1} at 506 DAP, respectively. On the other hand, of all organs, the highest P concentrations were detected in the fruit at 506 DAP, specifically in the crown and peel with 0.23 and 0.17 mg kg^{-1}, respectively. This higher requirement of N, P and K at the beginning of fruit development coincides with the fertilization recommendation Rebolledo Martínez *et al*., 2016, which suggest concluding fertilization before the anthesis stage.

Table 2. Nitrogen content in different organs of the pineapple plant because of planting density, Cultivar and planting density:Cultivar interaction.

Organ	Variation factor	N content (g plant^{-1})
Stem	30000 plants ha^{-1}	2.1282 ± 0.7975 a
	45000 plants ha^{-1}	1.7178 ± 0.2029 ab
	60000 plants ha^{-1}	1.3623 ± 0.5322 b
Leaf	30000 plants ha^{-1}*Champaka	7.9910 ± 1.2537 a
	45000 plants ha^{-1}*Champaka	5.3293 ± 1.1787 ab
	60000 plants ha^{-1}*Champaka	5.6094 ± 1.3148 ab
	30000 plants ha^{-1}*MD2	6.1478 ± 0.8981 ab
	45000 plants ha^{-1}*MD2	5.1996 ± 0.8602 b
	60000 plants ha^{-1}*MD2	4.5612 ± 0.4726 b
	30000 plants ha^{-1}*Smooth Cayenne	6.1770 ± 0.9529 ab
	45000 plants ha^{-1}* Smooth Cayenne	6.7258 ± 0.6935 ab
	60000 plants ha^{-1}* Smooth Cayenne	5.6238 ± 0.3948 ab
Peduncle	Champaka	0.1519 ± 0.0374 a
	MD-2	0.2371 ± 0.1263 a
	Smooth Cayenne	0.1508 ± 0.0627 a

Columns with the same letter are statistically equal according to Tukey's test ($p<0.05$). Arithmetic mean ± Standard deviation.

Table 3. Phosphorous content in different organs of the pineapple plant because of planting density, Cultivar and planting density:Cultivar interaction.

Organ	Variation factor	P content (g plant^{-1})
Stem	30000 plants ha^{-1}	0.2094 ± 0.0966 a
	45000 plants ha^{-1}	0.1509 ± 0.0328 a
	60000 plants ha^{-1}	0.1342 ± 0.0597 a
Leaf	30000 plants ha^{-1}	0.4988 ± 0.1990 a
	45000 plants ha^{-1}	0.3889 ± 0.0738 ab
	60000 plants ha^{-1}	0.3393 ± 0.0595 b
Peduncle	Champaka	0.0075 ± 0.0034 b
	MD-2	0.0155 ± 0.0077 a
	Smooth Cayenne	0.0105 ± 0.0070 ab
Fruit	30000 plants ha^{-1}*Champaka	0.5861 ± 0.0868 ab
	45000 plants ha^{-1}*Champaka	0.6109 ± 0.0263 ab
	60000 plants ha^{-1}*Champaka	0.4629 ± 0.0386 ab
	30000 plants ha^{-1}*MD2	0.5840 ± 0.0302 ab
	45000 plants ha^{-1}*MD2	0.4815 ± 0.1820 ab
	60000 plants ha^{-1}*MD2	0.4187 ± 0.0472 b
	30000 plants ha^{-1}*Smooth Cayenne	0.6614 ± 0.0690 a
	45000 plants ha^{-1}* Smooth Cayenne	0.6069 ± 0.0851 ab
	60000 plants ha^{-1}* Smooth Cayenne	0.6083 ± 0.0567 ab

Columns with the same letter are statistically equal according to Tukey's test ($p<0.05$). Arithmetic mean ± Standard deviation.

During plant development, the maximum N, P and K content in ‘Smooth Cayenne’ (12.56, 1.35, and 16.29 g plant^{-1}), ‘Champaka’ (14.86, 1.52, and 13.1 g plant^{-1}) and ‘MD-2’ (15.94, 1.17, and 14.96 g plant^{-1}), were detected with the lowest planting density, 30000 plants ha^{-1}, which is explained by the lower competition for water and nutrients between plants (Souza *et al*., 2019). Although the plant accumulates a smaller amount of N, P and K at the density of 60000 plants ha^{-1} (9.76–10.16, 0.87–1.13, and 10.90–14.60 g plant^{-1}), these values represent a content per hectare of 585-609, 58-68, and 611-875 kg ha^{-1}, these values are higher than the 377-445, 35-46, and 449-579 kg ha^{-1}, accumulated with the density of 30000 plants ha^{-1}.

Table 4. Potassium content in different organs of the pineapple plant because of planting density, Cultivar and planting density:Cultivar interaction.

Organ	Variation factor	K content (g plant^{-1})
Stem	30000 plants ha^{-1}	2.1708 ± 1.3480 a
	45000 plants ha^{-1}	1.5951 ± 0.4567 a
	60000 plants ha^{-1}	1.1926 ± 0.5373 a
Leaf	30000 plants ha^{-1}*Champaka	10.8871 ± 3.4371 a
	45000 plants ha^{-1}*Champaka	4.2484 ± 1.8515 b
	60000 plants ha^{-1}*Champaka	3.8557 ± 0.7019 b
	30000 plants ha^{-1}*MD2	7.5719 ± 1.7017 ab
	45000 plants ha^{-1}*MD2	6.7350 ± 0.6361 ab
	60000 plants ha^{-1}*MD2	5.4421 ± 2.1844 b
	30000 plants ha^{-1}*Smooth Cayenne	6.8495 ± 0.4787 ab
	45000 plants ha^{-1}* Smooth Cayenne	7.1349 ± 1.1348 ab
	60000 plants ha^{-1}* Smooth Cayenne	5.3083 ± 2.5827 b
Peduncle	Champaka	0.2675 ± 0.0655 b
	MD-2	0.4892 ± 0.1639 a
	Smooth Cayenne	0.2864 ± 0.0670 b
Fruit	30000 plants ha^{-1}*Champaka	5.4817 ± 0.5516 a
	45000 plants ha^{-1}*Champaka	4.7587 ± 0.3271 ab
	60000 plants ha^{-1}*Champaka	4.3216 ± 0.5666 ab
	30000 plants ha^{-1}*MD2	4.6852 ± 0.4437 ab
	45000 plants ha^{-1}*MD2	4.1636 ± 0.8661 ab
	60000 plants ha^{-1}*MD2	3.3846 ± 0.6116 b
	30000 plants ha^{-1}*Smooth Cayenne	5.3941 ± 0.3546 a
	45000 plants ha^{-1}* Smooth Cayenne	5.3899 ± 0.6026 a
	60000 plants ha^{-1}* Smooth Cayenne	5.1001 ± 0.7654 a

Columns with the same letter are statistically equal according to Tukey’s test ($p<0.05$). Arithmetic mean ± Standard deviation.

Greater nutrient content with higher planting density has also been detected in other producing regions of the world (Silva *et al*., 2009; Souza *et al*., 2019), this study confirms that the fertilization dose should increase as the number of plants per hectare increases.

In the fruit harvest, the lowest planting density presented the highest content of N, P and K per plant, while per unit area it was presented by the density of 60000 plants ha^{-1}. 'Smooth Cayenne' accumulated 9.725, 1.129 and 12.516 g $plant^{-1}$ of N, P and K and 587, 68, and 750 kg ha^{-1} of the same elements. On the other hand, 'Champaka' accumulated 9.626, 0.972, and 9.207 g $plant^{-1}$ of N, P, and K, which represents 577, 58, and 522 kg ha^{-1} of N, P, and K, respectively. In the case of 'MD-2', with the 7.931, 0.874, and 10.385 g $plant^{-1}$ of N, P and K, around of 475, 52, and 623 kg ha^{-1} are accumulated, respectively. This indicates that, at a density of 60000 plants ha^{-1}, 'Smooth Cayenne' and 'Champaka' require 112 and 102 kg extra of N compared to cv. 'MD-2', meanwhile, about 230 and 101 kg extra of K are required to be applied for 'Smooth Cayenne' and 'MD-2' compared to 'Champaka'.

It is important to point out that, at harvest time, 20-22, 39-54, and 29-47% of the total N, P, and K accumulated in the plant were accumulated in the fruit, values that changed to 19- 24, 45-50, and 32-34% for 'MD-2', as well as 20-24, 50-54, and 36-42% for 'Smooth Cayenne', respectively. These percentages indicate that, when 'Champaka' fruits of 2.2 to 2.5 kg $plant^{-1}$ are obtained, the amount of N, P and K removed from the production unit is around 84-123, 18-28 and 164-259 kg ha^{-1}, respectively. In the case of 'MD-2', with fruits from 1.8 to 2.1 kg $plant^{-1}$, 50-110, 18-25 and 141-203 kg ha^{-1} of N, P and K are removed, respectively. As for 'Smooth cayenne', with fruits from 2.3 to 2.7 kg $plant^{-1}$, about 84-123, 18-28 and 164-259 kg ha^{-1} of N, P and K, respectively, withdraw from the production unit. These results corroborate the recommendations of Rebolledo Martínez *et al*. (2016) and Uriza-Ávila *et al*. (2018), who, for pineapple plantations that will be kept in the field to obtain a second or third fruit harvest, indicate applying between 40% and 50% of the fertilization dose applied for the first fruit harvest. The results mainly support the dose of N and K, however, in the case of P, in the three Cultivars and in the three planting densities, the percentage accumulated in the fruit was less than 25%. Therefore, for plantations that will be maintained for a second or third fruit harvest, the P recommendation should be less than 30% of the dose applied at the beginning of the plantation.

CONCLUSIONS

The results indicate that, regardless of the Cultivar and planting density, the highest content of N and K occurs during fruit development, while the highest content of P occurs close to harvest. The greatest amount of N, P, and K accumulates in the leaves, mainly before the fruit develops. A higher content of N, P, and K per plant occurs at the lowest planting density, however, the highest content per hectare occurs at the highest planting density. 'Smooth Cayenne' is the cultivar that accumulates the greatest amount of N and K, while the least amount of N and P is accumulated from the production unit with 'MD-2' fruits. This information must be considered in the nutritional program of commercial pineapple plantations, especially if some of the cultivars studied are used.

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