Deficiencies of nitrogen, calcium, and micronutrients are the most limiting factors for growth and yield of smell pepper plants[1]

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ABSTRACT

Cultivation and commercialization of Capsicum pepper have great importance in Brazil. This work assessed the influence of omission of macro and micronutrients on the growth and mineral nutrition of sweet pepper plants (*Capsicum chinense* Jacquin). The research was carried out in a greenhouse with washed sand as substrate. The experimental design was completely randomized with five replications and eight treatments: complete (control), omission of N, P, K, Ca, Mg, S, and micronutrients (B, Cu, Fe, Mn and Zn). The plants were submitted to the treatments when they reached an average height of 20 cm and the nutrient solution was supplied by percolation in plastic pots and renewed every 15 days. Nutrients omission affected negatively plant growth as a whole. The omission of N, Ca, and micronutrients greatly reduced sweet pepper yield. The *C. chinense* plants presented the sequence by dry matter production of shoots and roots in descending order: COMP > OP > OS > OK > Omg > ON > Oca > OMicro.

Keywords: *Capsicum chinense* Jacquin; omission of nutrients; nutrient export.

INTRODUCTION

Smell pepper (*Capsicum chinense* Jacquin) is an important crop worldwide, mainly for its use in cooking, its flavor, aroma and biofunctional compounds (Valdovinos-Nava *et al.*, 2020). Peppers are important sources of natural antioxidants, such as vitamins C, E, and carotenoids. In addition, peppers have antimicrobial and analgesic properties and are used in the treatment of rheumatoid arthritis, osteoarthritis, diabetic neuropathy, and neuralgias (Loizzo *et al.*, 2015).

Nevertheless, increasing pepper production and quality through fertilization is a challenge for producers, as few studies have investigated the nutritional management of the crop (Alejo-Santiago *et al.*, 2015; Das *et al.*, 2016; Moreno-Salazar *et al.*, 2020; Valdovinos-Nava *et al.*, 2020). Therefore, studies should investigate the impacts of nutritional management on pepper growth and production and mainly regarding the disturbances caused by nutrients omission to plant metabolism.

Understanding the role of nutrients in the metabolism of pepper plants is necessary to determine nutritional demand and direct fertilizer recommendations. Additionally, knowledge of the nutritional status of plants is crucial to increase crop yield and improve nutrient management (Prado, 2021). Thus, studies on nutrients omission are needed to understand the disturbances caused by nutrient absence and to identify the most limiting nutrients in plant metabolism.

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Nutrient deficiencies are harmful to plants, as deficiencies reduce the productive potential of crops (Mardanluo *et al.*, 2018; Silva *et al.*, 2018; Joshi *et al.*, 2022). Nutrients act in different activities of plant metabolism, participating as integral elements of organic compounds (N and S), in the acquisition and energy use and for the genome (P), in the structural formation of the cell wall (Ca and B), as well as integral compounds of enzymes and other essential molecules of metabolism (Mg, Fe, Mn, Zn, Cu, Mo, and Ni) and in the activation and control of enzyme activity (K, Cl, Mg, Ca, Mn, Fe, Zn and Cu). Nutrient deficiencies are expressed in the morphological and productive characteristics of plants, causing significant damage (Prado, 2021). However, little is known about the symptoms and impacts of nutrient deficiency in peppercorns.

Therefore, investigations of nutritional disturbances caused by nutrients omission on the growth and productive performance of smell pepper. This research evaluated the nutritional disorders caused by nutrients omission on plant growth and crop yield of smell pepper, as well as impacts on nutrient concentrations and export.

MATERIAL AND METHOD

The study was conducted in a greenhouse at the Campus of the Federal Rural University of Amazon (UFRA) in the city of Capanema, Pará State, Brazil. We used washed sand as substrate and the experimental design was completely randomized with five replicates and eight treatments: complete (macro and micronutrients; control), individual omission of N, P, K, Ca, Mg, S, and micronutrients (B, Cu, Fe, Mn, and Zn).

The seeds were sown in medium plastic cups (200 ml) containing black earth substrate collected at the 0 to 20 cm layer, when the plants reached between 20 and 30 cm of height and the most vigorous was selected and transplanted by two samples to pots with a capacity of 5 dm^3 of washed sand. The samples were thinned 30 days after planting, leaving one plant per pot. The plants were initially irrigated for 10 days with demineralized water. The nutrient solution used was Bolle-Jones (1957), which has shown good results in experiments with crops in the Amazon region. The solution was initially diluted in 50% of the total load and later with 30 days total load 100% of the solution, with a pH of 5.5. In the first 30 days, the solution was applied to all plants thus nutrients omission was not induced. After this period, nutrients omission was started in each treatment. The nutrient solution was applied daily and every 15 days, washing with deionized water to eliminate salt excess.

The symptoms of deficiency related to the omission of each nutrient were described from the omission beginning until their complete definition, accompanied by photographs. The plants were collected and washed with distilled water after the visual symptoms of deficiency. The entire plant was divided into organs: leaves, stem + branches (shoots), roots, and fruits and placed in kraft paper bags to dry in a greenhouse with forced air circulation at 70 ºC until they reached constant mass. For relative growth (RG), we calculated the ratio of total dry mass of plants in the omission of each nutrient and the total dry mass obtained in the complete treatment (C).

Leaf concentration of N, P, K, Ca, Mg, S, and micronutrients (B, Cu, Fe, Mn and Zn) were determined according to the methodology described by Malavolta *et al.* (1997). Nutrient accumulation was calculated by multiplying nutrient concentration by the dry matter (DM) content (Equation 1). We measured plant height, the number of leaves, the number of fruits, and stem circumference at 2.5 cm from the vase surface. We also measured the DM of leaves, shoots, roots, fruits, and total. Macronutrient export was calculated based on the C, the estimate based on the production of 1 t ha^{-1} of fresh fruit, considering the nutrient efficiency.

$$Accumulation = Concentration \times Dry\,matter \quad (Equation\ 1)$$

The variance analysis was performed using the F test in the R studio program and significance was obtained by the Tukey test at 5% probability of the data referring to the variables: plant height, stem diameter, number of leaves and fruits, and the dry mass of leaves, shoots, roots, fruits, and total. The “Radar chart Method” was used to compare the biometric results and relative growth of nutrients in young smell pepper plants (Nunes *et al.*, 2005).

RESULTS AND DISCUSSION

Growth

The analyses of the biometric variables, using the plant height as an indicator, showed that the control treatment (C) did not present significant differences when compared to the omission of P, K, and S (Table 1). However, the omission of N, Ca, and micronutrients were limiting for the growth. N is required in biomass synthesis, as it is involved in the photosynthetic processes of plants, contributing to the increase of photoassimilates (Partelli, 2011; Souza & Fernandes, 2018). Therefore, N deficiency reduces leaf area and plant biomass, drastically decreasing the plant photosynthetic capacity and thus the plant size (Prado, 2021). Ca deficiency reduces plant size, since Ca is strongly retained in the cell wall, which is one of its main functions in the plant structure, representing between 30% and 50% of the total Ca of the plant (Prado, 2021).

Table 1: Plant height (PH), steam diameter (SD), number of leaves (NL), number of fruits (FRUITS), relative plant height growth (RPH), relative growth of stem diameter (RSD), relative growth in the number of leaves (RNF), relative growth in the number of fruits (RF FRUITS), production of shoot dry matter (SDM), root dry matter (RDM) and total dry matter (TDM), depending on the treatments

Treatment	PH	SD	NL	Fruits	RPH	RSD	RNF	RF	SDM	RDM	TDM
	cm	mm			--------- % -------				----------- g -----------		
C	51.4a	11.32a	120.4a	23.4a	100.0	100.0	100.0	100.0	15.89a	12.15a	28.04a
NO	43.6b	7.38cd	64.6c	8.2e	84.8	65.2	53.7	35.0	9.66e	5.75de	15.41e
PO	52.2a	7.40cd	69.2c	10.0de	101.5	65.4	57.5	42.7	14.45b	8.44b	22.89b
KO	51.6a	7.33cd	85.0b	14.4bc	100.3	64.8	70.6	61.5	11.58cd	6.85cd	18.43d
MgO	45.2b	7.32cg	84.4b	15.8bc	87.9	64.7	70.1	67.5	7.55f	5.82de	13.37f
CaO	43.6b	7.94bc	76.6bc	9.2de	84.8	70.1	63.6	39.3	10.46de	5.77de	16.23e
SO	53.0a	8.47b	109.0a	16.4b	103.1	74.8	90.5	70.1	12.83c	7.79bc	20.63c
MicO	45.4b	6.91d	77.0bc	12.4cd	88.3	61.0	64.0	53.0	6.98f	5.03e	12.01f
CV (%)	5.77	6.65	8.15	13.17	-	-	-	-	6.11	7.98	5.19
SDM	5.43	1.03	13.59	3.51	-	-	-	-	14.004	11.768	19.560

Means followed by different letters in the columns differ from each other, by the Tukey test at 5% probability. Treatments: Complete (C); nitrogen omission (NO); phosphorus omission (PO); potassium omission (KO); magnesium omission (MgO); calcium omission (CaO); sulphur omission (SO); omission of micronutrients (MicO). Means followed by letters in the columns differ significantly by the Tukey test at 5% probability.

Omission of all nutrients limited stem diameter (SD) when compared to the control treatment (C) with a maximum value of 11.32 mm. The treatment with micronutrient omission showed the greatest limitations of SD, with a relative growth of 61.04%; however, these limitations were did not differ from N, P, and K omissions (Table 1). Micronutrients are considered to be indispensable to crops in Brazil, especially zinc (Zn) and B. In the Brazilian Amazon, Pará State, B is the most limiting micronutrient for palm, açai, and coconut crops (Matos *et al.,* 2017). B deficiency promotes changes in the synthesis of elements that comprise the cell wall – pectin, hemicellulose, lignin precursors – leading to a collapse of the plant stem (Prado, 2021).

Except for the omission of S, all other treatments reduced the number of leaves when compared to the control and N omission was the most limiting, but it did not differ from the omissions of P, Ca, and micronutrients (Table 1). The omission of micronutrients also caused a reduction in plant height compared to the control treatment (Table 1). Micronutrient deficiency reduced plant growth, as micronutrients have different enzymatic activities and are involved in different metabolic processes in plants, such as photosynthesis and respiration (Prado, 2021). The descending order of the number of leaves was: control (C) > sulfur omission (OS) > potassium omission (OK) > magnesium omission (Omg) > micronutrients omission (Omicro) > calcium omission (Oca) > phosphorus omission (OP) > nitrogen omission (ON).

Visual diagnosis of nutrient deficiency

N omission most affected relative growth when compared to the other treatments. Thus, in the treatment with N omission, plant growth was 53.65%, a reduction of 46.35% (Table 1). Similar results in tomato plants were observed, belonging to the same family of smell pepper in which the decrease in N doses promoted a reduction in leaf area and in the number of fruits (Andriolo *et al.*, 2004).

Regarding the number of fruits, the control reached the highest number with 24.40 fruits, while N omission was the most limiting factor with a reduction of 64.96% (Table 1). The descending order of the number of fruits was: ON >

Oca > OP > Omicro > OK > Omg > OS > C. In olive plants, DM also showed greater reduction with the omission of N, Ca, and B (Souza *et al.*, 2019). However, in cupuaçu plants (*Theobroma grandiflorum*), K, B and S had the most growth limiting nutrients (Almeida *et al.*, 2021).

Plants grown in complete nutrient solution © showed good development, without visual symptoms of nutritional deficiency, representing maximum performance in all graphs by the forms of balls. Values above the average are methods that use graphics, described in fertigram "full ball", and the "withers ball" format refers to the treatment that is deficient, results below average (Nunes *et al.*, 2005). Regarding the variable plant height, the treatments with omission of S, P and K were assumed to be the other treatments (Figure 1a), that is, above average, exceeding or approaching the complete treatme©(C), having full ball behavior, but omissions of N, Ca, Mg, and micronutrients, compromised the height of the smell pepper in a withered ball model (Figure 1a).

For the stem diameter (Figure 1b), all treatments behaved in the form of a wilted ball, that is, below the average, thus affecting the variable, However, the treatments with omissions of N, P, K, and micronutrients were closer to zero and therefore with values below average, when compared to the complete treatment. The number of leaves and number of fruits was affected by all omissions, mainly NO, PO, and CaO, a different behavior for SO, which was higher than the other treatments (Figures 1c and 1d).

The relative growth of the variables analyzed (Figure 1), namely plant height, stem diameter, number of leaves, and number of fruits, was affected mainly with omissions in increasing order N > Ca > P = micronutrients.

Limitations to the relative growth of plant height were expressed in N/Ca > Mg = micronutrients in the form of a wilted ball, with results below average, when compared to the control, with a full ball behavior in P, K, and S omissions, that is, above average, without interfering in the relative growth of plant height. The relative growth of the stem diameter was affected by all omissions, represented in a withered ball model, with values lower than the control one.

Relative Growth

Omissions of macronutrients and micronutrients compromised the relative growth of the number of leaves and the number of pepper smell fruits, all below the average in relation to the control treatment (C), in the form of a wilted ball, with emphasis on treatments with omission of N, P, and Ca, which were the most limiting factors.

Plant growth can be evaluated through relative growth, as plant efficiency to accumulate DM is estimated as a function of omissions. Therefore, plant growth during the experimental period was the most affected by N omission with 59% in the relative growth of all variables analyzed in relation to the control treatment C (100%) (Figures 1 and 2). N is a constituent of the molecule of chlorophyll, proteins, amino acids, and nucleic acids; thus, N deficiency alters the enzymatic activity in the biochemical phase of photosynthesis and the metabolism of carbohydrates and N, decreasing the photosynthetic rate and, therefore, plant growth (Taiz & Zeiger, 2013). As a constituent of all enzymes, N acts in the processes of ionic absorption, photosynthesis, respiration, multiplication, and cell differentiation (Malavolta *et al.*, 1997).

The treatment with P omission limited the growth of smell peppers, because stem diameter, number of leaves, and number of fruits in wilted ball behavior were lower than the treatment without omission (Figure 1). This shows that P is actively linked to the metabolism of various molecules, such as starch, fats, and proteins. P also plays a role in plant structure and is directly involved with energy transfer and storage (Aquino *et al.*, 2019). Thus, P omission limits plant growth, reducing energy production and transport (Araújo *et al.*, 2016).

K omission showed the smallest stem diameter, differing from the control treatment (C) (Figure 1b). K is important to osmotic regulation, opening and closing of stomata, influencing the transport and storage of carbohydrates, protein synthesis, enzymatic activity, and starch synthesis in the leaf (Armengaud *et al.*, 2009). K omission on plant height acted in a full ball model, similar to the control treatment (C) (Figure 1a), and therefore did not affect plant height.

Mg omission affected size, structure, and function of chloroplasts. Mg is a constituent of the chlorophyll molecule, and acts activating enzymes involved in the processes of respiration, photosynthesis, and synthesis of nucleic acids (Taiz & Zeiger, 2013). These features were analyzed here, because 72% was obtained in the growth of all variables in Figure 1, with a withered ball model, below average when compared to the control treatment C, with Mg omission.

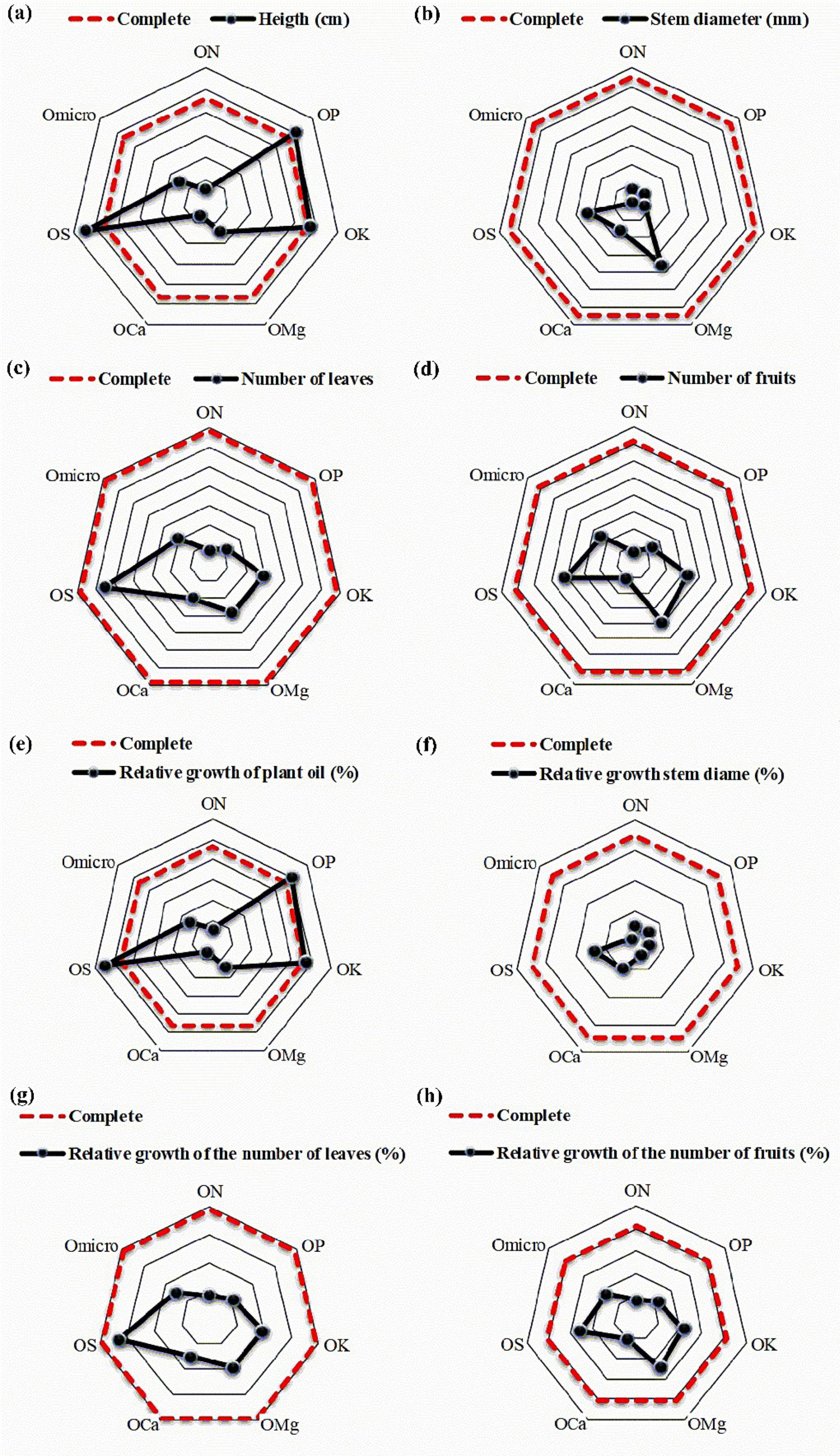

Figure 1: Plant height (a), stem diameter (b), number of leaves (c), number of fruits (d), Relative growth of plant oil (RPH %; e), relative growth stem diameter (RSD %; f), relative growth of the number of leaves (RNF % - g), relative growth of the number of fruits (RF FRUITS %; h), depending on the treatments.

Ca after N affected the relative growth of the smell pepper plants by 64%, where Ca omission caused problems to plant height, stem diameter, number of leaves and fruits. Ca plays a crucial role in plant growth, as it is one of the main components of the cell wall, responsible for binding pectin molecules (White & Broadley, 2009). S was one of the nutrients that least affected growth of smell pepper plants, with a growth of 84% when compared to the control treatment (C) (100%), possibly due to lower requirement (Solanaceae) for S (Haag & Homa, 1968).

On the other hand, micronutrients omission (B, Cu, Fe, Mn and Zn) affected plant height, stem diameter, number of leaves, and number of fruits as well as relative growth, affected at the same proportion as P and Ca omission, although required at smaller amounts, P and Ca play an important role for plant metabolism.

Dry matter production

Regarding shoot dry matter (SDM) production, omissions of micronutrients, Ca and N most affected the crop, with a reduction of 56.08%, 52.39%, and 39.23%, respectively, when compared to the control treatment (C) (Table 1). Similar results were observed in studies with pepper and ornamental pepper where Ca and N omissions most affected plant growth and DM production (Coelho *et al.*, 2014; Fernandes & Haag, 1972).

Regarding root dry matter (RDM), similarly to shoots, the most limiting nutrients were omission of micronutrients, N, Mg, and Ca at 58.6%, 52.68%, 52.52%, and 52.07%, respectively, lower than the control treatment (C). Symptoms of Ca deficiency occur earlier and more severely thus Ca is not redistributed, affecting plant growth and root development (Prado, 2021).

Figure 2 shows the relative growth (RG) in DM production and the control treatment The was considered a reference (RG = 100%). The treatments with omission of micronutrients and Ca presented the lowest growth percentages. The omission of other nutrients also affected the SDM and RDM production of plants. P omission was less limiting and did not differ statistically from S omission in RDM. the control treatment (c) provided root system growth slightly higher than the shoot, a balanced relationship possibly increased by nutrient absorption.

Ca omission caused a drastic reduction in the growth of long pepper plants 53 days after the beginning of treatment (Viegas *et al.*, 2014). Ca deficiency affected tomato plants, reducing growth by 70% compared to the complete plants (Baboulène *et al.*, 2007), in agreement with the results obtained in our study. Therefore, the sequence presented by the plants, considering the total DM production at the descending order was: COMP > OP > OS > OK > OMg > ON > Oca > OMicro.

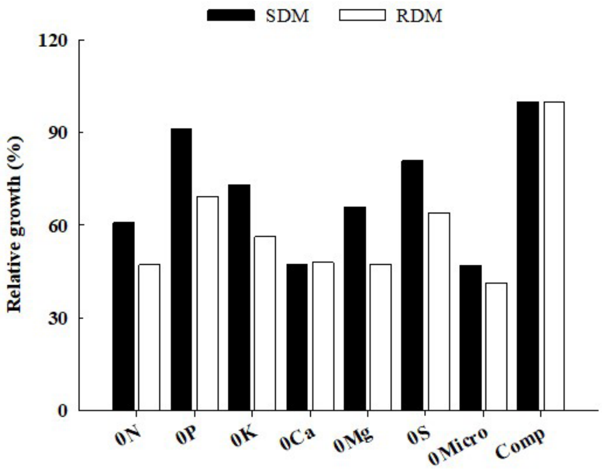

Figure 2: Relative growth in shoot dry matter (SDM) and root system (RDM) of smell pepper plants in response to complete treatments (C); nitrogen omission (ON); phosphorus omission (OP); potassium omission (OK); magnesium omission (OMg); calcium omission (OCa); sulphur omission (OS); omission of micronutrients (OMic: B, Cu, Fe, Mn and Zn).

Visual diagnosis depending on the treatments applied

The first symptoms of N deficiency started 24 days after the start of treatments. The plants showed initial symptoms of a pale green of older leaves, evolving until they became chlorotic, and finally necrotic (Figure 3b). Leaf concentration in N deficient plants was 21.4 g kg^{-1}, while in plants that did not show symptoms, leaf concentration of N was 22.2 g kg^{-1} (Table 2), similar to long pepper plants (Veígas *et al.*, 2013). The stain first appears on older leaves due to the lack of chlorophyll that is no longer synthesized or is degraded to the detriment of newer leaves or for fruit formation (Prado, 2021). N omission reduced the number of fruits (Figure 3j), drastically decreased plant size (Figure 3r) and the root system.

Visual symptoms of P deficiency were observed 24 days after the application of the treatments, when compared with the control treatment (C), a pale green and narrowing was observed in older leaves (Figure 3c). Leaf concentration in plants with visual symptoms of P deficiency was 3.9 g kg^{-1} and without symptoms, leaf concentration was 4.5 g kg^{-1}

of P (Table 2). Similar symptoms were observed in cherry plants, which presented lighter green color and progressed to more accentuated yellowing until total loss of color (Viégas *et al.*, 2012). P deficient in smell pepper plants reduce fruit size (Figure 3k) and root system (Figure 7c). P deficiency affects biomass production and the breathing process, slowing plant growth (Fernandes & Haag, 1972).

Visual symptoms of K deficiency started 49 days from the beginning of the treatments. Initially, yellowing occurred on the leaf edges at the apex, near the ribs, evolving to necrosis. In the most advanced stage of the symptom, necrosis occurs at the leaf apex (Figure 3d). K deficiency in smell pepper also reduces the number of fruits (Figure 3l) and the root system (Figure 3aa).

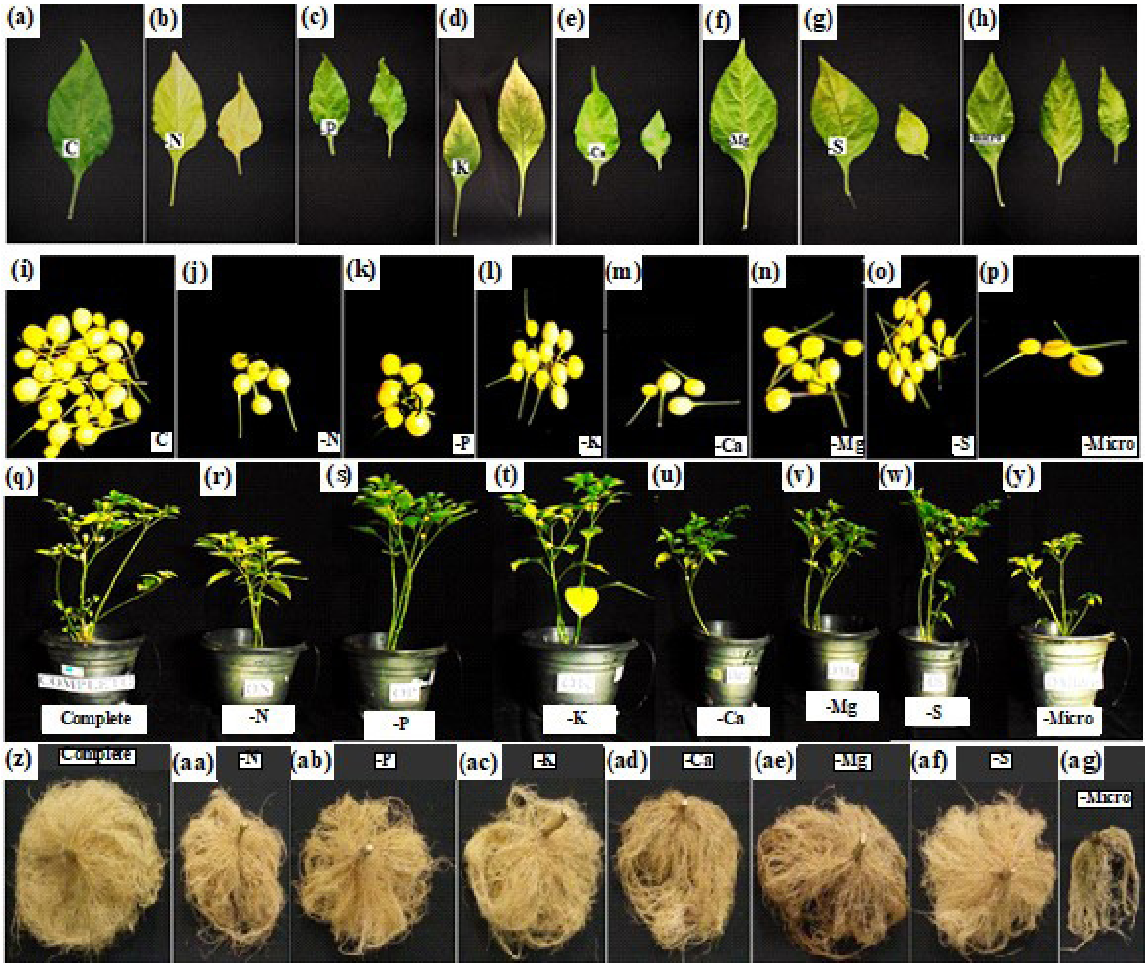

Figure 3: Leaves, fruits, shoots and roots of smell pepper plants (*Capsicum chinense* Jacquin) without visual symptoms of nutrient deficiency (C = complete; a, i, q, z) and with symptoms of nitrogen (-N; b, j, r, aa), phosphorus (-P; c, k, s, ab), potassium (-K; d, l, t, ac), calcium (-Ca; e, m, u, ad), magnesium (-Mg; f, n, v, ae), sulfur (-S; g, o, w, af) and micronutrients (-Micro; h, p, y, ag).

Plants with visual symptoms of K deficiency, leaf concentrations were 25 g kg^{-1}, while without symptoms, leaf concentrations were 28 g kg^{-1} of K (Table 2). K is the most abundant cation thus it is absorbed at large quantities by the roots and plays an important role in the plant energy status, in the translocation and storage of assimilates, and in the maintenance of water in the tissues (Prado, 2021). Symptoms of K deficiency in general are characterized by chlorosis and necrosis at the edges of leaves, initially in older leaves, and premature senescence of the leaves may occur (Prado, 2021).

Symptoms of Ca deficiency appeared 48 days after the beginning of treatments and were more pronounced in the reduction of plant size (Figure 3u). In the leaves, size reduced with mild chlorosis throughout the extension, coiled in the abaxial direction, and the ribs remained with a darker shade (Figure 3d). Fruits showed a reduction in size and number (Figure 3m) and plant height (Figure 3u) and the number of roots also decreased (Figure 3ad). Ca leaf concentration in deficient plants were 1.2 g kg^{-1} and in plants without visual symptoms of deficiency, Ca leaf concentration was 1.5 g kg^{-1} (Table 2). The size and number of fruits reduced (Figure 3e). The common symptom for Ca deficiency is chlorosis in younger leaves, from the edges to the center, and the symptoms occur in fruits of tomato plants due to the competition of the fruit for Ca in the xylem, since leaves sweat more (Lima *et al.*, 2018). Ca deficiency particularly affects root growth, affecting plant metabolism and causing the appearance of polyploidy nuclei, contrite nuclei, and amniotic divisions, growth is paralyzed and darkening occurs, causing the death of the root system (Prado, 2021). Symptoms of deformation in leaves due to Ca deficiency have been observed in several plants grown in the Amazon, such as long pepper (Veígas *et al.*, 2013), *Swietenia macrophylla* (Viégas *et al.*, 2012) and ipeca (Viegas *et al.*, 2014). Young plant organs, mainly leaves, develop symptoms of Ca deficiency as Ca is not remobilized in the plant. Ca deficiency can cause a gelatinous appearance at the tips and edges of the leaves, as well as at growing points, due to the need for Ca pectate for cell wall formation (Prado, 2021).

Table 2: Leaf concentrations in nutritional deficiency and sufficiency, exportation of nutrients (kg t^{-1}) and export of macronutrients by smell pepper for the production of 1 t ha^{-1} of fresh fruits. Export corrected by efficiency (kg/t/fresh fruits) by the fruits of smell piper, depending on the treatments

Treatments		**Deficiency (g kg^{-1})**	**Sufficiency (g kg^{-1})**	**Exportation (g fruit^{-1})**	**Mean**	**kg t^{-1}**
N		21.4	22.2	0.043	7.12	6.039
P		3.9	4.5	0.008	8.11	0.986
K		2.5	28.0	0.049	9.34	5.246
Ca		1.2	1.1	0.002	6.36	0.314
Mg		2.8	2.9	0.005	7.14	0.700
S		4.0	4.5	0.008	11.3	0.708
Micronutrients		**mg kg^{-1}**	**mg kg^{-1}**	**mg fruit^{-1}**	**Mean**	**g t^{-1}**
B		17.8	22.8	0.044	10.03	4.387
Cu		2.5	3.5	0.004	10.03	0.399
Fe		60.0	75.0	0.147	10.03	14.656
Mn		5.0	15.0	0.009	10.03	0.897
Zn		23.5	26.5	0.052	10.03	5.184
Export	N	P_2O_5	K_2O	Ca	Mg	S
Macro (kg/t /fresh fruits)	6	2.1	6.3	0.3	0.7	0.7
Efficiency (%)	60	30	70	60	50	40
ECE (kg/t/fresh fruits)	10	7	9	0.5	1.4	1.4

Macro: macronutrients; ECE: Export Corrected by Efficiency (kg/t/fresh fruits).

Symptoms of Mg deficiency started 45 days after the start of treatments with slight yellowing of older leaves, initially with a pale green between the ribs, which were progressively evolving until the leaves became chlorotic (Figure 3f) with a reduction in the number of fruits (Figure 3n) at plant height (Figure 3f) and a significant decrease in root system (Figure 3ae). The leaf levels of Mg with visual symptoms of deficiency were 2.8 g kg^{-1} and in plants without symptoms, Mg levels were 2.9 g kg^{-1}. Therefore, leaf concentration was very similar with and without symptoms of deficiencies (Table 2). Fernandes & Haag (1972) reported similar results of Mg deficiency in chili culture. Haag & Homa (1968) also found similar results for scarlet eggplant, which belong to the same family of the smelling pepper tree. Mg plays vital functions in plant metabolism and structure and it is a constituent of the chlorophyll molecule and chloroplasts with an energy conversion function (Prado, 2021). Mg is an enzymatic activator, more than any other element, functioning as a cofactor of almost all phosphorylated enzymes (ATP or ADP), crucial in the process of photosynthesis, respiration, synthesis reactions of organic compounds, ionic absorption, and in the mechanical work performed by the plant (Lima *et al.*, 2018). Due to Mg redistribution, symptoms of deficiency appear first in older leaves with yellowing between the ribs in extreme cases of deficiency with the ribs remaining green, similar to our results. In Mg deficient plants, the concentration of non-reducing sugars and starch increases, causing losses to carbohydrate metabolism and impairing transport in phloem (Tewari *et al.*, 2006).

Symptoms of S deficiency started 49 days after the application of the treatments. Similar to N deficiency, differing from this by presenting initial yellowing in the younger leaves with a pale green and subsequent generalized chlorosis in younger leaves (Figure 3g). S omission caused a reduction in stem diameter, number of fruits (Figure 3o), and root system (Figure 3af). Leaf concentration in plants with visual symptoms of S deficiency was 4 g kg^{-1}, while without symptoms, leaf concentration was 4.5 g kg^{-1} of S (Table 2). The visual symptoms reported in this study are similar to those reported by Haag & Homa (1968) in eggplants, with mild chlorination in young leaves and the fading color of the fruits.

According to Malavolta *et al*. (1997), S distribution occurs in the acroptera sense, moving from the plant base upwards, the ability of the plant to do the reverse process, that is, from the top down, is very small, and therefore the symptoms of deficiency of this nutrient arise first in younger organs, such as the leaves. S has a structural and metabolic function. Structurally, S is a component of the structure of proteins, peptides, and amino acids, which are components directly linked to the physiological and vital processes of plants. Thus, S deficiency causes metabolic disorders to plants, decreasing the photosynthesis and respiratory activities and reducing fat content and accumulation of soluble carbohydrates.

The symptoms of micronutrient deficiency began 25 days after the beginning of the treatments and were evident mainly in the reduction of plant size (Figure 3y) and of size and number of fruits (Figure 3p). Small leaves with mild chlorosis and some younger ones became deformed, wrinkled, indicating possible B deficiency. Similar symptoms have been reported in scarlet eggplants (Haag & Homa, 1968), belonging to the same family of smell pepper *(Solanaceae),* when subjected to B omission. B and Zn are most limiting to crops in Brazil. B acts in plant metabolism as an enzyme activator, cell wall constituent, and its main functions are related to cell structure and associated peptic substances, such as the middle lamella. Zn is an important nutrient for the maintenance of auxin and visual symptoms are the reduction of apical growth.

In general, visual symptoms of macronutrient and micronutrient deficiencies occurred in terms of precocity in the following order: N and P with the occurrence of the first symptoms with 24 days of the beginning of the omissions, followed by the omission of micronutrients with 25 days, later Mg with 45 days, Ca with 48 days, and K and S with 49 days. Thus, smell pepper plants are more sensitive to N, P, and micronutrient deficiencies.

Nutrient export

The most exported macronutrients based on the control treatment (C) by the smell pepper fruits *(C. chinense)* followed the decreasing order: K > N > P > S > Mg > Ca. Considering the spacing of pepper plants of 1.20 line x 0.80 between plants with density of 10,040 plants, the estimated productivity is 291,160 fruits ha^{-1}. Fe, B, and Zn were the most exported micronutrients by fruits with 0.147, 0.044, and 0.052 g per fruit, respectively (Table 2). Cu and Mn with values of 0.004 and 0.009 g the least exported (Table 2).

The amount exported to by N was 0.043 g $fruit^{-1}$, which corresponds to 6,039 kg per ton of fruit. N directly affects plant growth, flowering, and production. The organoleptic quality of fruits can also be affected by the presence, absence, or even deficiency or nutritional imbalance caused by the N link (Souza & Fernandes, 2018).

P exports were 0.080 g/fruit, which corresponds to 0.986 kg per ton of fruit. A study with nutrient accumulation in flavored pepper (with Lupita) yielded 3.3 kg ha^{-1} of P in the fruits under field conditions (Oka, 2017). According to Malavolta *et al.*, (1997), when the P is supplied to the plant, after leaf senescence, up to 60% of the P can be conducted to other parts via phloem, mainly in the new organs and in the developing fruits, increasing the P content, as P is the second most required nutrient by the fruits.

The amount exported of K was higher than the other macronutrients of 0.049 grams per fruit, equivalent to

5,246 kg per ton of fruits. Similar results were reported for mineral nutrition in chilli plants *(Capsicum annum)* and K concentration was higher in fruits (Albuquerque *et al.*, 2012). This fact corroborates Malavolta *et al*. (1997) in that P is highly soluble in water, conferring mobility to P in plants, mainly in younger organs or in developing fruits.

Ca exported 0.002 grams per fruit, that is, 0.314 kg t^{-1} of fruits and Ca was the least exported macronutrient. Ca participates in the structural functions of the plant, such as the cell wall and plasma membrane. Thus, the Ca supply increases production of Ca oxalate in tissues and, through nutrient solution, this increase occurs in the leaves, but not necessarily in the fruits (supplied via phloem) because Ca has low mobility in the plant (Lima *et al.*, 2018).

Mg exported 0.005 grams per fruit and S exported 0.008, totaling 0.700 and 0.708 kg per ton of fruit, respectively. Mg is a macronutrient essentially related to nucleophilic ligands by means of ionic (mostly) or covalent bonds, such as chlorophyll molecule. According to Lima *et al.* (2018), 5 to 25% of total Mg is part of the chlorophyll molecule. Thus, unlike Ca, Mg is very mobile in phloem and its export by the fruit depends on the translocation efficiency, occurring primarily for younger leaves or growth points. Due to the results of export of smell pepper fruits by macronutrients based on the C, the estimate for composting based on the production of 1 t ha^{-1} of fresh fruits is shown in Table 2. The efficiency of nutrients was considered in the calculations.

CONCLUSIONS

- The omission of macronutrients and micronutrients in the nutrient solution promotes the occurrence of visual symptoms of deficiency in young smell pepper plants with reduced leaf content of these nutrients.
- The precocity in the manifestation of visual symptoms of deficiency are N > P > micronutrients > Mg > Ca > K = S
- The omission of macronutrients and micronutrients limits the development of biometric variables and the production of total DM when compared to the complete treatment (C), and Ca and micronutrients are the most limiting.
- In nutrient solution, the visual symptoms of macronutrient and micronutrient deficiency in young plants of smell pepper was expressed by leaf contents of 21.4, 3.9, 25, 1.2, 2.8. 4.0 g kg^{-1} of N, P, K, Ca, Mg, and S, respectively.
- The nutrients most exported by the smell pepper fruits are N and K.

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