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# Growth and nutrition of *Passiflora edulis* submitted to saline stress after silicon application

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**Abstract** – We carried out greenhouse experiment to evaluate the effect of silicon (Si) on growth and mineral nutrition of yellow passion fruit (*Passiflora edulis*) submitted to saline stress in a nutritive solution. The experiment comprised a completely randomized design in a 5x4 factorial scheme: five NaCl concentrations (0; 7.5; 15; 30 and 60 mmol $L^{-1}$) and four $SiO_2$ concentrations (0; 0.5; 1.0 and 1.5 mmol $L^{-1}$) with four replicates. At the end of 35 days, we measured stem diameter, leaves, stem, and roots dry matter, as well as the macronutrient, Na, Cl, and Si leaf accumulation in plants. In most cases, the increase in NaCl supply in a nutritive solution reduced the dry matter of roots, stem, and leaves. The $SiO_2$ supply attenuated the effect on higher tested saline stress (30 and 60 mmol $L^{-1}$ NaCl) on roots and stem dry matter. The application of 0.5 mmol $L^{-1}$ of $SiO_2$ reduced the deleterious effect of salinity on all macronutrients absorption in yellow passion fruit cultivated in a nutritive solution.
**Index terms:** Beneficial elements, Fruticulture, Mineral Nutrition, Sodium.

# Crescimento e nutrição de *Passiflora edulis* submetido ao estresse salino após aplicação de silício

**Resumo** - Realizou-se um experimento em casa de vegetação para avaliar o efeito do silício (Si) no crescimento e na nutrição mineral do maracujazeiro-amarelo (*Passiflora edulis*) submetido ao estresse salino em solução nutritiva. Utilizou-se o delineamento inteiramente casualizado em esquema fatorial 5x4: cinco concentrações de NaCl (0; 7,5; 15; 30 e 60 mmol $L^{-1}$) e quatro concentrações de $SiO_2$ (0; 0,5; 1,0 e 1,5 mmol $L^{-1}$) com quatro repetições. Ao final de 35 dias, mensuraram-se o diâmetro do caule, a matéria seca das folhas, caule e raízes, além dos teores de macronutrientes, Na, Cl e Si nas folhas das plantas. Na maioria dos casos, o aumento no fornecimento de NaCl em solução nutritiva reduziu a produção de matéria seca das raízes, do caule e das folhas das plantas. O suprimento de $SiO_2$ atenuou o efeito do maior estresse salino (30 e 60 mmol $L^{-1}$ NaCl) na matéria seca das raízes e do caule. A aplicação de 0,5 mmol $L^{-1}$ de $SiO_2$ reduziu o efeito deletério da salinidade na absorção de todos os macronutrientes pelo maracujazeiro-amarelo cultivado em solução nutritiva.
**Termos de indexação:** Elementos benéficos, fruticultura, nutrição mineral, sódio.

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## Introduction

Passion fruit (*Passiflora edulis*) grows properly in tropical and subtropical regions, with average temperatures between 20 and 32 ºC (RUGGIERO et al., 1998). Brazil is the largest producer of passion fruit in the world, producing 602,651 tons of fruit in 2018, with 14 Mg ha$^{-1}$ year$^{-1}$ of average yield (IBGE, 2019). The Northeast and Southeast are the main passion fruit producing regions in Brazil with 68% and 13%, respectively, and planted areas are concentrated in the states of Bahia, Ceará, Santa Catarina, Minas Gerais, and Rio Grande do Norte. The northeastern region harvested area in 2018 totaled 29,144 ha (IBGE, 2019). Passion fruit has great importance in the agricultural sector due to the physicochemical and therapeutic characteristics of the fruits, high productivity, and great acceptance in the world market. The passion fruit culture gained prominence in Brazil from the beginning of the 1970s; nevertheless, in the 1950s, processing plants of passion fruit juice were already operating in the country (FALEIRO; JUNQUEIRA, 2016). Although production has decreased since 2013, Brazil continues to be the world's largest consumer and producer of yellow passion fruit.

Nutrient demand for passion fruit plants increases proportionally to its biomass production. This situation affects the crop development, reflecting on the absorption of several nutrients. It is known that yellow passion fruit demands a nutritional balance, with higher requirements for nitrogen (N), potassium (K) and calcium (Ca) (NASCIMENTO et al., 2011). Several soil physicochemical characteristics influence absorption of these macronutrients, including features that affect the chemical composition of soil solution (FAQUIN, 2005). Among these factors, increase in salts concentration in the soil solution stands out, which, in most cases, is associated to the increased availability of sodium (Na) and chloride (Cl) (ISAYENKOV; MAATHUIS, 2019), inducing physiological and biochemical changes in plants (BHATTARAI et al., 2020). Excess of these elements increases soil solution electrical conductivity, with consequent increase in the osmotic potential, hindering water absorption capacity of plants (SANDERS, 2020). Furthermore, saline stress causes competition for root absorption sites with consequent reduction in the absorption of nutrients that are essential for plant growth (MARSCHNER, 2012). Crops show different responses to salinity, some are sensitive to low salt concentrations, while others can grow under high salt concentrations, depending on their capacity for osmotic adaptation. Yellow passion fruit, for example, is considered salt-sensitive (FREIRE et al., 2010; DIAS et al., 2011). Thus, a better understanding of the effects of saline stress on plant growth and nutrients absorption and assessment of products capable of reducing crop toxicity are essential to increase crop productivity.

Studies show that silicon (Si) has beneficial effects on many crops, especially under biotic and abiotic stress conditions, such as pests and disease attacks, water stress tolerance (CRUSCIOL et al., 2009; KORNDÖRFER; SOUZA, 2018), and saline and osmotic stresses (COSKUN et al., 2016). Costa et al. (2016) found that higher Si supply to yellow passion fruit plants increased stem diameter and yield of stem fresh matter and leaf dry matter. Ashraf et al. (2010) studied sugarcane saline stress reduction by Si supply and reported lower root and shoot dry matter yields when cultivated with NaCl, higher yields in Si presence, and intermediate yields when submitted to NaCl and Si simultaneously. Under stress conditions, Si is deposited on the walls of epidermal cells of some species, along with the stomata, reducing the transpiration rate thus reducing the plant water consumption (MARSCHNER, 2012). We hypothesize that the yellow passion fruit absorbs and accumulates Si in the leaves and increases tolerance to saline stress. Given the increase of passion fruit planted area in Brazil and the possibility of using areas under salinity conditions, we evaluated responses on growth and macronutrients, Na, Cl, and Si accumulation on passion fruit plants submitted to different Si concentrations and under different salinity conditions.

## Material and methods

The experiment was conducted at the Soil Science Department greenhouse at the Federal University of Lavras, Minas Gerais State (Brazil), from January to April (120 days). Seeds of yellow passion fruit (*Passiflora edulis sims* f. *Flavicarpa*, Degener) were sown in plastic trays containing vermiculite. Moisture was kept with distilled water containing 0.01 mmol L$^{-1}$ of calcium sulfate dihydrate ($CaSO_4$ $2H_2O$). Germinated seeds were transferred and kept in a container (36 L) for seven days with 25% of the original nutritive solution concentration. Afterward, the nutrient solution concentration was replaced to 50% of the original concentration, remaining this way for another seven days (HOAGLAND; ARNON, 1950). After this acclimation period, seedlings were transferred to containers with a capacity of 3 L with the Si ($Na_2SiO_3$) and NaCl concentrations designated per treatment. Sodium amount, added via silicate, was subtracted from the original NaCl. Sodium metasilicate ($Na_2SiO_3$) presented 18% of sodium oxide ($Na_2O$) and 63% of silicon dioxide ($SiO_2$), while NaCl had 52.5% of $Na_2O$.

The trial was performed in a randomized complete design, in a 5x4 factorial scheme, with four replications per treatment, and one plant per pot. Factors referred to concentrations of NaCl (0.0, 7.5, 15, 30 e 60 mmol L$^{-1}$) and $SiO_2$ (0.0, 0.5, 1.0 and 1.5 mmol L$^{-1}$). Concentrations were applied simultaneously and in combination with the nutritive solution with pH adjusted to 6.0 using

HCl or NaOH (0.1 mol $L^{-1}$) (HOAGLAND; ARNON, 1950), which was measured and corrected at a 7-day interval. Thirty-five days after treatment application, we measured the stem diameter of plants with a digital caliper. Afterward, plants were harvested and separated into leaves, stems, and roots and oven dried (65 ºC) until constant weight to determine dry matter production. Leaves were ground for the chemical analysis using methodologies described in Malavolta et al. (1997). The extract obtained by nitric-perchloric digestion was used to determine phosphorus (P) concentrations by colorimetry. Calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectrophotometry, potassium (K) and sodium (Na) by flame emission photometry, and sulfur (S) by turbidimetry of barium sulfate. The total N concentrations were determined by the Kjeldahl semi-micro method, using distillation and titration. The Chlorine (Cl) concentrations, extracted with distilled water (agitation), were determined by silver nitrate titrating, while silicon (Si) was extracted by the colorimetric method of "molybdenum blue" (FURLANI; GALO, 1978). The leaf nutrient accumulation was calculated by multiplying the leaf nutrient concentrations and dry matter in the leaves. The analyses of variance ($p<0.05$) and the regression analysis were performed using the SISVAR statistical program (FERREIRA, 2011) where equations were adjusted according to the factors isolated or the interaction between them.

## Results and discussion

**Growth of passion fruit plants under NaCl and $SiO_2$ concentrations**

The interaction between the factors NaCl and $SiO_2$ evaluated affected the stem diameter (SD) of plants (Figure 1). Regardless of the concentrations of $SiO_2$ evaluated, there was a linear reduction of up to 29% in SD as NaCl increased in the solution concentration.

In the absence of NaCl, with the application of 0.5 mmol $L^{-1}$ of $SiO_2$, SD of plants was higher, presenting an average value of 0.87 cm. Although the $SiO_2$ levels did not reduce the negative effect of saline stress, SD remained approximately constant between 7.5 and 15 mmol $L^{-1}$ of NaCl. Costa et al. (2016) found that Si supply (0.21 g $pot^{-1}$) promoted greater estimated SD (0.23 cm) of yellow passion fruit cultivated in pots with a commercial substrate. The plants in the current study did not present a mechanism to withstand saline stress caused by higher NaCl concentrations, providing a SD reduction. Cavalcante et al. (2002) also observed a reduction in SD of passion fruit plants due to the increase in salinity.

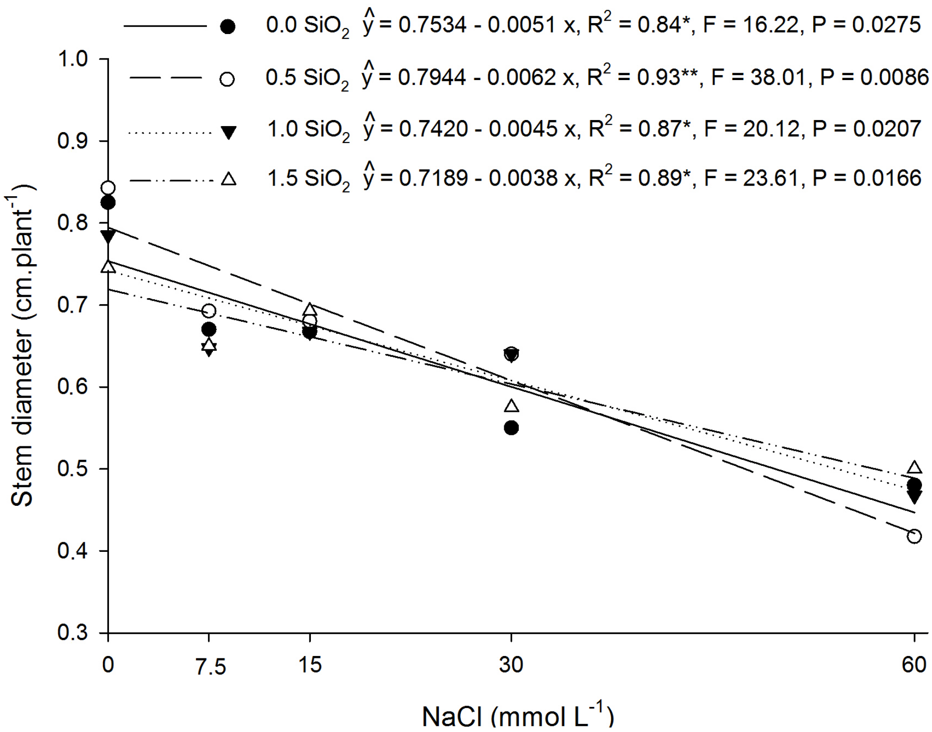


**Figure 1.** Stem diameter (SD) of yellow passion fruit as a function of NaCl and $SiO_2$ levels supply in the nutrient solution; ** $p<0.01$, * $p<0.05$.

The interaction between the NaCl and $SiO_2$ factors evaluated affected the root dry matter (RDM) of the plants at 0, 0.5, and 1.0 mmol $L^{-1}$ of $SiO_2$ (Figure 2a). The RDM reduced linearly with increasing salt stress up to the concentration of 60 mmol $L^{-1}$ of NaCl, in the absence of $SiO_2$ and with an application of 0.5 and 1.0 mmol $L^{-1}$ of $SiO_2$. Although $SiO_2$ levels did not exert total control of saline stress on RDM, in the presence of $SiO_2$, the reduction of RDM was less accentuated in greater saline concentrations of 30 and 60 mmol $L^{-1}$ of NaCl (Figure 2a). Similarly, the literature reports the mitigating effect of salt stress by supplying Si to plants, such as sugar cane, canola, and wheat (ASHRAF et al., 2010; HASHEMI et al., 2010). In addition, Ashraf et al. (2010) evidenced saline stress mitigation in sugarcane plants obtaining lower RDM values when only NaCl was supplied, higher values when only Si was supplied, and intermediate values when Si was combined with NaCl.

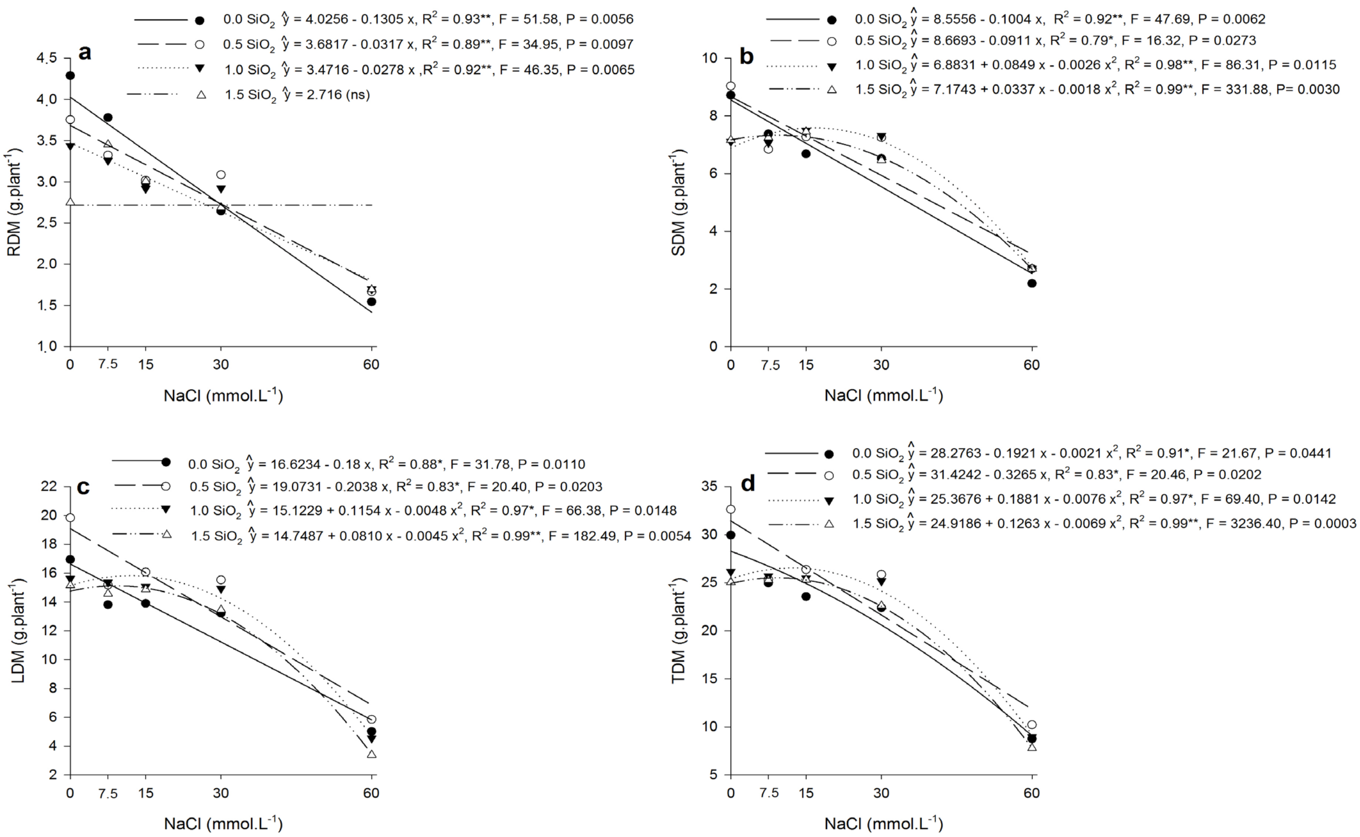


**Figure 2**. Root dry matter, RDM (a), stem dry matter, SDM (b), leaf dry matter, LDM (c), total dry matter, TDM (d) of yellow passion fruit as a function of NaCl and $SiO_2$ levels supply in the nutrient solution. ** $p<0.01$, * $p<0.05$, ns - $p>0.05$.

The interaction between NaCl and $SiO_2$ factors affected the plants stem dry matter (SDM), both in the absence and presence of $SiO_2$ levels (Figure 2b). In the absence of Si application, SDM decreased 15% and 75% at 7.5 and 60 mmol $L^{-1}$ of NaCl concentrations, respectively (compared to 0 mmol $L^{-1}$ of NaCl). With the application of 0.5 mmol $L^{-1}$ of $SiO_2$, SDM reduced 24 and 70% for plants cultivated at 7.5 and 60 mmol $L^{-1}$ of NaCl, respectively. On the other hand, with application of 1.5 mmol $L^{-1}$ of $SiO_2$, SDM reached a maximum production of 7.3 g $plant^{-1}$ with plants submitted to the estimated concentration of 9.4 mmol $L^{-1}$ of NaCl, reducing with the highest levels of NaCl.

We observed that the $SiO_2$ supply did not contribute to an increase in SDM (Figure 2b), unlike reports by Costa et al. (2016). The authors found that the highest fresh matter was reached with the estimated concentration of 109.1 mmol $L^{-1}$ of $SiO_2$. Despite the different responses between the Si concentrations tested, there was a general stability trend for SDM up to 30 mmol $L^{-1}$ of NaCl and a significant reduction in the highest concentration of NaCl. Hashemi et al. (2010) tested Si concentrations to alleviate saline stress in canola plants and observed lower aerial dry matter in plants submitted to NaCl, higher when Si was supplied, and intermediate when both sources were mixed.

The interaction between NaCl and $SiO_2$ factors affected the leaf dry matter (LDM) in the absence and presence of $SiO_2$ levels, similar to the responses obtained for SDM (Figures 2b and 2c). When Si was not applied, there was a LDM reduction of 19% (7.5 mmol $L^{-1}$ NaCl) and of 70% (60 mmol $L^{-1}$ NaCl). The application of 0.5 mmol $L^{-1}$ of $SiO_2$ promoted a LDM loss of 24% in the condition of lower saline stress (7.5 mmol $L^{-1}$ NaCl), while the plants grown at the concentration of 60 mmol $L^{-1}$ NaCl decreased their LDM by 71%. Therefore, regardless of Si supply, salinity provided a LDM reduction in yellow passion fruit. This species is considered sensitive to salts (FREIRE et al., 2010; DIAS et al., 2011). In the presence of 1.0 and 1.5 mmol $L^{-1}$ of $SiO_2$, the maximum LDM accumulation was 15.8 and 15.1 g $plant^{-1}$ at the estimated concentrations of 12.0 and 9.0 mmol $L^{-1}$ of NaCl, respectively, reducing with the highest levels of NaCl. The application of 0.5 mmol $L^{-1}$ of $SiO_2$ increased LDM production in the absence of NaCl, with an average of 19.0 g $plant^{-1}$. However, up to an estimated concentration of 12.0 mmol $L^{-1}$ of NaCl, the application of 1.0 mmol $L^{-1}$ of $SiO_2$ promoted an increase in the LDM production, similar to the increase obtained in the absence of NaCl (Figure 2c). For LDM, a general stability trend was observed for 0 to 30 mmol $L^{-1}$ NaCl range. The values of total dry matter (TDM) presented similar behavior to the compartments already discussed (Figure 2d). For cultivated plants at concentrations of 0, 0.5, 1.0 and 1.5 mmol $L^{-1}$ $SiO_2$, higher Na supply (60 mmol $L^{-1}$ NaCl) caused TDM losses of 71, 69, 66 and 69%, respectively. This fact indicates that the Si supply was efficient in reducing saline stress on TDM production, even small, caused by higher Na concentration. In general, Si-accumulating plants may present a decrease in salt stress, caused by the decrease in $Na^+$ and $Cl^-$ absorption. After absorption and deposition of Si on root cell walls, Si reduces the flow of $Na^+$ and $Cl^-$ via apoplast, forming binding sites for salts that reduce its absorption (MA et al., 2006; COSKUN et al., 2016). Regarding Si deposition under the cuticles of leaves, Romero-Aranda et al. (2006) suggest a decrease in cuticular transpiration with a consequent dilution of salts in the leaves, reducing their toxic effects.

The results of the current study confirm the susceptibility of yellow passion fruit to saline stress (FREIRE et al., 2010; DIAS et al., 2011), which caused a reduction in the growth parameters evaluated. This may be related to various physiological and biochemical changes that result from excess Na and Cl in the nutrient solution, reducing plant growth (BHATTARAI et al., 2020). According to Munns (2005), salt stress can occur in two phases. The first phase is ruled by the osmotic effect due to the high concentration of salts in the root zone, while the second phase is governed by the toxic effects caused by the increase in the concentration of salts in foliar tissues. The presence of high root zone salt concentration causes higher osmotic pressure in the soil solution than in plant cells, reducing the ability of plants to absorb water and nutrients (MUNNS et al., 2006). Under severe conditions of saline stress, a solution containing high osmotic pressure causes loss of water from the cells in the roots, leading to wilting and foliar senescence. (MUNNS, 2002; SANDERS, 2020). Osmotic stress initially reduces leaf growth and eventually causes a reduction in shoot development and reproductive growth (MUNNS; TESTER, 2008). In the aerial part of plants, excess of salts constrains the photosynthetic apparatus, as well as the functioning of various enzymes responsible for plant metabolism, which may compromise plant growth. (BHATTARAI et al., 2020). The strategies involved in attenuating the effects of salinity in the soil involve the use of tolerant cultivars, as well as the increase in the supply of chemical elements that act as antagonists to salt stress in plants, such as K (ISAYENKOV; MAATHUIS, 2019). Recently, the role of Si in mitigating the harmful effects of salinity for plant growth has been investigated (ASHRAF et al., 2010; COSTA et al., 2016).

**Na, Cl, and $SiO_2$ leaf accumulation**

There was no influence of $SiO_2$ concentrations on Na leaf accumulation (Figure 3a); however, Na leaf accumulation increased abruptly due to NaCl supply up to 15 mmol $L^{-1}$. This fact can be explained by the increase in Na uptake and the relatively constant production of LDM up to the concentration of 15 mmol $L^{-1}$ of NaCl (Figure 2c). With the highest Na leaf concentration average (264.9 g $kg^{-1}$), the plants submitted to 60 mmol $L^{-1}$ of NaCl had low LDM yield and showed a decrease of 52% in Na leaf accumulation compared to plants submitted to 15 mmol $L^{-1}$ (Figure 3a). The average Na accumulation in leaves of plants cultivated with 0, 0.5, 1.0 and 1.5 mmol $L^{-1}$ $SiO_2$ was 1.47, 1.62, 1.61, and 1.55 g $plant^{-1}$, respectively. These results are in conformity with Munns (1993), who observed that the aerial part of plants was sensitive to saline stress, due to the imbalances between the cations, caused by the complex interactions of the transport system inside the plant. In addition, it is known that high NaCl levels cause cell walls protein denaturation and disruption, causing $Ca^{2+}$ displacement of cell wall sites, increasing Na influx (TAIZ et al., 2017). However, Miranda et al. (2010) observed in the pre-dwarf cashew quadratic increase of Na leaf accumulation after 0.5 and 1.0 mmol $L^{-1}$ of $SiO_2$ supply and the concentration of 1.5 mmol $L^{-1}$ of $SiO_2$ showed a linear response with increased of NaCl concentrations.

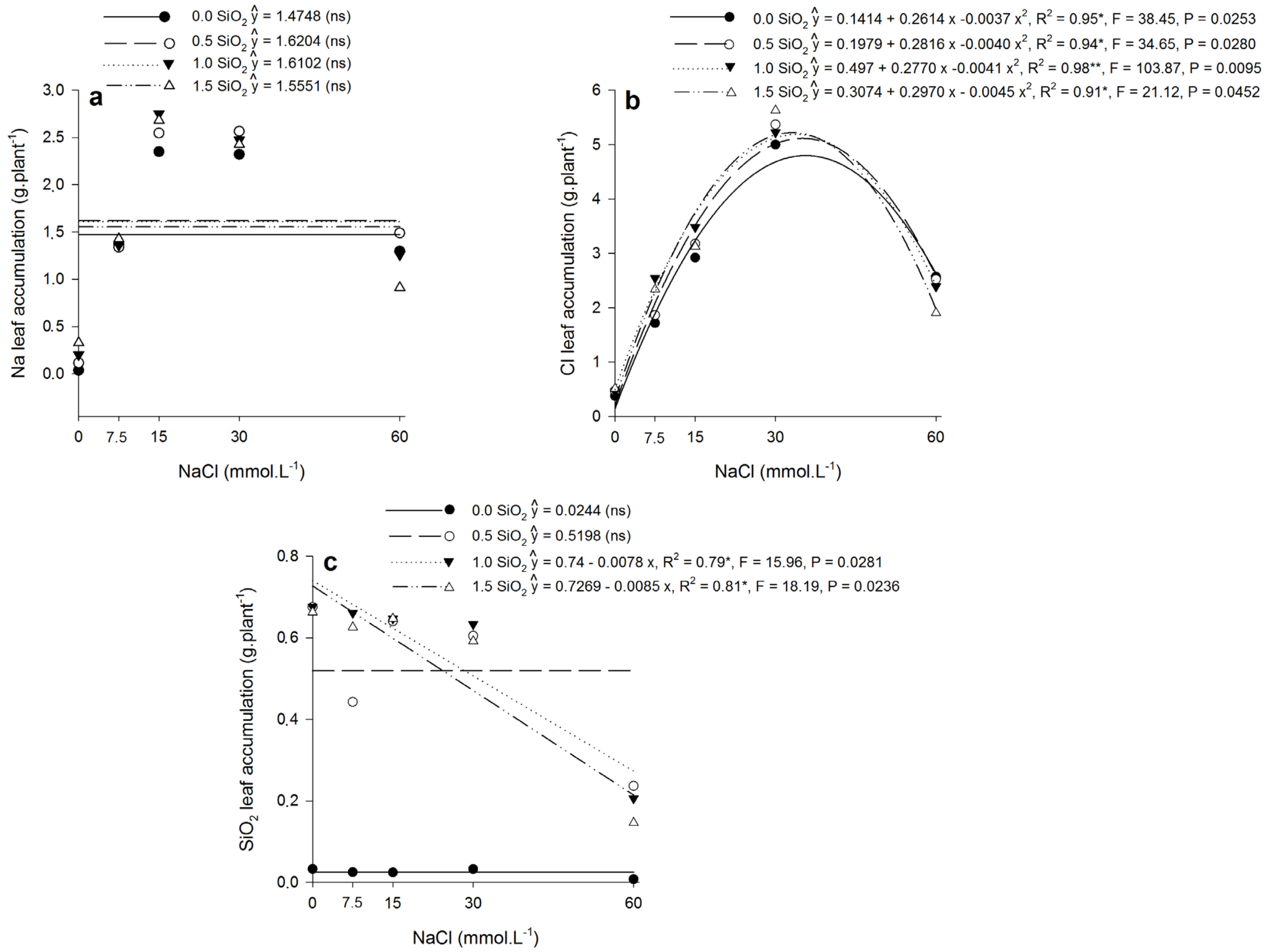


**Figure 3**. Na (a), Cl (b) and $SiO_2$ (c) leaf accumulation in yellow passion fruit as a function of NaCl and $SiO_2$ levels supply in the nutrient solution. ** $p<0.01$, * $p<0.05$, ns - $p>0.05$.

The Cl leaf accumulation presented quadratic responses due to NaCl supply (Figure 3b). According to the generated equations, the maximum Cl leaf accumulation was observed at 1.5 mmol $L^{-1}$ of $SiO_2$ (5.2 g $plant^{-1}$) and the lowest occurred in the absence of $SiO_2$ (4.8 g $plant^{-1}$). Peaks of Cl leaf accumulation occurred between the estimated concentrations of 33 and 36 mmol $L^{-1}$ of NaCl. Similarly, Miranda et al. (2010) observed an increase in Cl leaf accumulation in dwarf cashew plants, submitted to NaCl levels in a nutritive solution. For 0, 0.5, and 1.5 mmol $L^{-1}$ $SiO_2$, the same authors obtained a linear response regarding Cl leaf accumulation. Only 1.0 mmol $L^{-1}$ of $SiO_2$ presented a quadratic response. In the current study, $SiO_2$ levels tested were not sufficient to decrease Cl leaf accumulation, causing nutritional imbalance, leading to a sharp reduction of dry matter production at the highest NaCl concentrations (Figure 2). Passion fruit plants are dicotyledons and thus they do not accumulate $SiO_2$ (MARSCHNER, 2012), besides they are classified as sensitive to the presence of salts (FREIRE et al., 2010; DIAS et al., 2011) and do not prevent the transport of high quantities of Cl ions to the aerial part, as observed in the current experiment (Figure 2b).

The interaction between the factors NaCl and $SiO_2$ altered $SiO_2$ leaf accumulation only at 1.0 and 1.5 mmol $L^{-1}$ of $SiO_2$ (Figure 3c). At these $SiO_2$ concentrations, $SiO_2$ leaf accumulation reduced linearly with increasing NaCl concentrations in solution. The highest $SiO_2$ concentration (1.5 mmol $L^{-1}$) showed a sharp decrease in $SiO_2$ leaf accumulation with NaCl increase compared to 1.0 mmol $L^{-1}$ of $SiO_2$. According to the equations generated, maximum $SiO_2$ leaf accumulation (0.74 g $plant^{-1}$) occurred at 1.0 mmol $L^{-1}$ of $SiO_2$ in the absence of NaCl (Figure 3c). Between 0 and 30 mmol $L^{-1}$ of NaCl, the average $SiO_2$ leaf accumulation remained between 0.58 and 0.68 g $plant^{-1}$. A large reduction in $SiO_2$ leaf accumulation values (69%) was observed for 60 mmol $L^{-1}$ of NaCl. Miranda et al. (2010) observed that after the application of 0.5 and 1.0 mmol $L^{-1}$ of $SiO_2$, $SiO_2$ leaf accumulation increased in a quadratic manner. Even though the passion fruit is not a Si-accumulating species (MARSCHNER, 2012), it is important to provide Si to the seedling formation process and its utilization in passion fruit fertilizations, due to the beneficial morpho-anatomical and physiological changes promoted by the element (COSTA et al., 2018). Costa et al. (2018) showed an increase of up to 49% in the photosynthetic rate of passion fruit plants fertilized with Si, in addition to an increase in transpiration, stomatal conductance, and stomata polar/equatorial diameter ratio.

### N, P, and K leaf accumulation

NaCl concentrations at 0.5, 1.0, and 1.5 mmol $L^{-1}$ of $SiO_2$ affected N leaf accumulation (Figure 4a). However, there was no significant response to NaCl on N leaf accumulation in the absence of $SiO_2$ with 5.04 g $plant^{-1}$ on average. The application of 0.5 mmol $L^{-1}$ of $SiO_2$ decreased N leaf accumulation with an increase of NaCl concentrations. Concentration of 1.0 and 1.5 mmol $L^{-1}$ of $SiO_2$ increased N leaf accumulation with an increase of NaCl concentrations up to 30 and 15 mmol $L^{-1}$ of NaCl, respectively, decreasing afterward. The highest N leaf accumulation was found with the concentration of 0.5 mmol $L^{-1}$ of $SiO_2$ (7.66 g $plant^{-1}$) at 15 mmol $L^{-1}$ of NaCl solution. The greatest reductions in N leaf accumulation were observed with the highest levels of NaCl (60 mmol $L^{-1}$), at all $SiO_2$ concentrations.

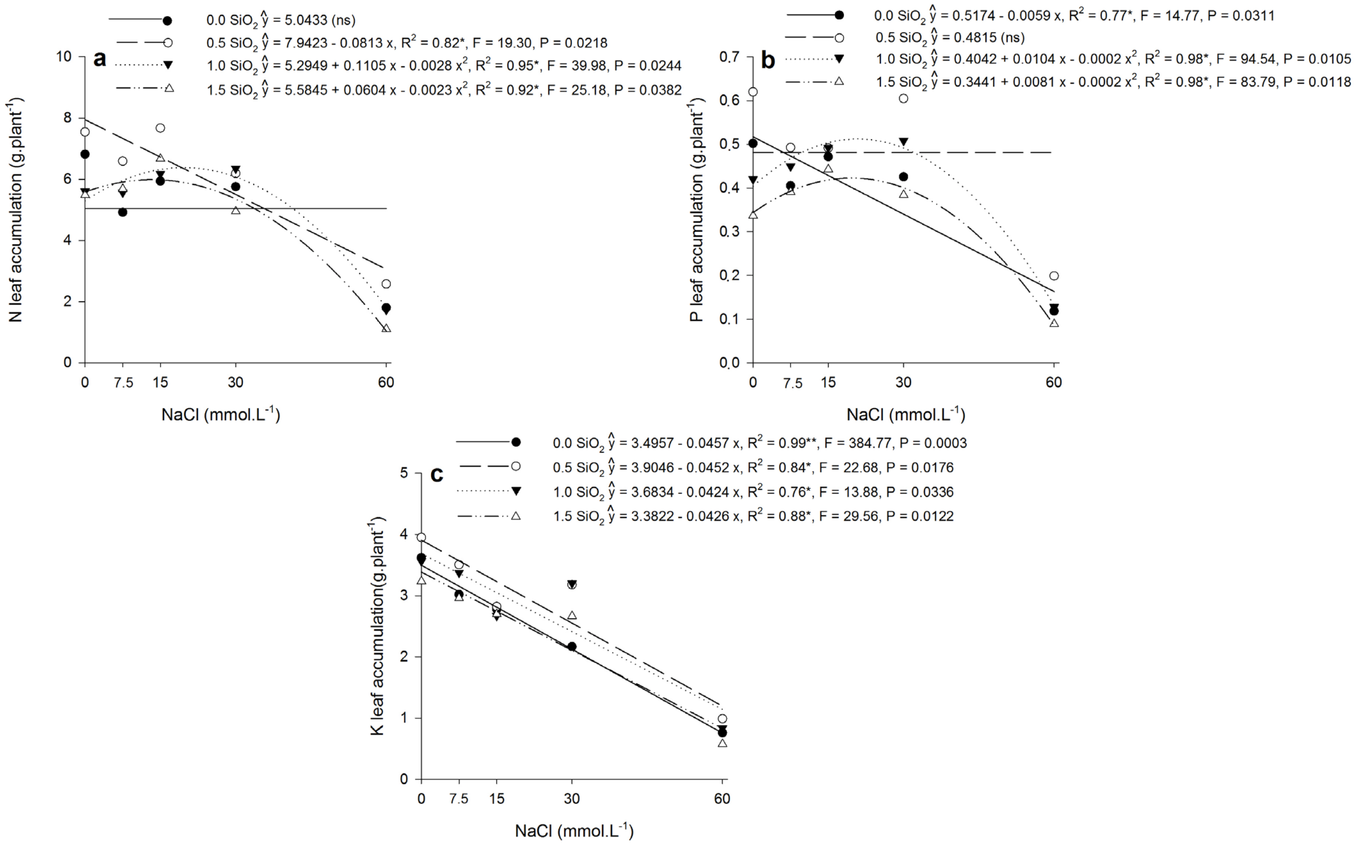


**Figure 4.** N (a), P (b) and K (c) leaf accumulation of yellow passion fruit as function of NaCl and $SiO_2$ levels supply in the nutrient solution. ** $p<0.01$; * $p<0.05$; ns - $p>0.05$.

Although the mechanisms are still unknown, the supply of $SiO_2$ has the potential to promote growth benefits in saline environments for some plant species (COSKUN et al., 2016). However, in the case of yellow passion fruit under the conditions in the present study, $SiO_2$ controlling the saline stress effect was not observed in the plants submitted to 60 mmol $L^{-1}$ of NaCl during the exposure period to the nutritive solution, because of its low salinity tolerance (DIAS et al., 2011). Miranda et al. (2005) evaluated *Moringa oleifera* plants submitted to NaCl levels in a nutritive solution and observed a linear reduction of N leaf accumulation as the NaCl concentration increased. The effect between salinity and N is complex since it is dependent on the crop, saline composition, N amount, and its ionic form in the solution (nitric or ammoniacal forms) (DING et al., 2010; GUO et al., 2017).

The interaction between NaCl and $SiO_2$ factors influenced P accumulation in the leaves (Figure 4b). In the Si absence in the solution, there was a reduction in P leaf accumulation from 0.50 (0 mmol $L^{-1}$ of NaCl) to 0.12 (60 mmol $L^{-1}$ of NaCl) g $plant^{-1}$. For 0.5 mmol $L^{-1}$ of $SiO_2$, NaCl concentrations did not influence P leaf accumulation (average 0.48 g $plant^{-1}$). The application of 1.0 and 1.5 mmol $L^{-1}$ of $SiO_2$ showed a peak in P leaf accumulation of 0.51 and 0.44 g $plant^{-1}$ at concentrations 30 and 15 mmol $L^{-1}$ of NaCl, respectively, decreasing its accumulation from these doses onward. Al-Karaki (1997) observed that a decrease in P leaf accumulation could be related to the low activity of phosphate ions in the solution with the increase of NaCl, causing a nutritional imbalance due to Cl excess in plant tissues. However, Turan et al. (2010) observed increases in P accumulation in maize, probably due to a synergistic effect of Na, which involves P absorption.

For all $SiO_2$ concentrations applied, K accumulation in the leaves decreased with an increase of NaCl concentrations (Figure 4c). K leaf accumulation reduced from 3.62 to 0.76 g plant$^{-1}$ (0 mmol L$^{-1}$ of $SiO_2$), from 3.95 to 0.99 g plant$^{-1}$ (0.5 mmol L$^{-1}$ of $SiO_2$), from 3.56 to 0.84 g plant$^{-1}$ (1.0 mmol L$^{-1}$ of $SiO_2$) and from 3.23 to 0.57 g plant$^{-1}$ (1.5 mmol L$^{-1}$ of $SiO_2$), comparing the condition without NaCl supply to higher saline stress (60 mmol L$^{-1}$ of NaCl). Ions $Na^+$ can perform part of the $K^+$ osmotic function due to its similar ionic properties; however, $Na^+$ toxicity is mainly based on competition with $K^+$ in sites for protein transport, therefore, the low cytosolic ratio of K/Na causes the deleterious effects of high $Na^+$ absorption (WU et al., 2018). According to Taiz et al. (2017), the decrease of $K^+$ in plants causes serious imbalances since $K^+$ acts in osmotic processes, protein synthesis, and membrane permeability. Then, keeping adequate $K^+$ levels in the cytoplasm during saline stress is critical for homeostatic $K^+$ (MARSCHNER, 2012; ISAYENKOV; MAATHUIS, 2019).

**Ca, Mg, and S leaf accumulation**

Except for Ca leaf accumulation in plants treated with 1.0 and 1.5 mmol L$^{-1}$ of $SiO_2$ and for S leaf accumulation (1.0 mmol L$^{-1}$ of $SiO_2$), the increase of NaCl supply decreased the accumulation of Ca, Mg, and S in the leaves, regardless of $SiO_2$ concentrations applied (Figures 5a, 5b, 5c). Compared to the absence of Na supply at 15 mmol L$^{-1}$ of NaCl, Ca leaf accumulation reduced from 2.98 to 1.88 g plant$^{-1}$ (0 mmol L$^{-1}$ of $SiO_2$) and from 2.84 to 2.19 g plant$^{-1}$ (0.5 mmol L$^{-1}$ of $SiO_2$), respectively (Figure 5a). The highest NaCl concentration promoted the largest reduction in Ca leaf accumulation (average 77%); however, the supply of 0.5 mmol L$^{-1}$ of $SiO_2$ relieved the increased saline stress (60 mmol L$^{-1}$ of NaCl). Mehrabanjoubani et al. (2015) observed greater reductions in Ca accumulation in cotton and wheat plants with $SiO_2$ application compared to those without Si application. According to the authors, $SiO_2$ promoted a higher leaf area and reduction of the transpiration rate.

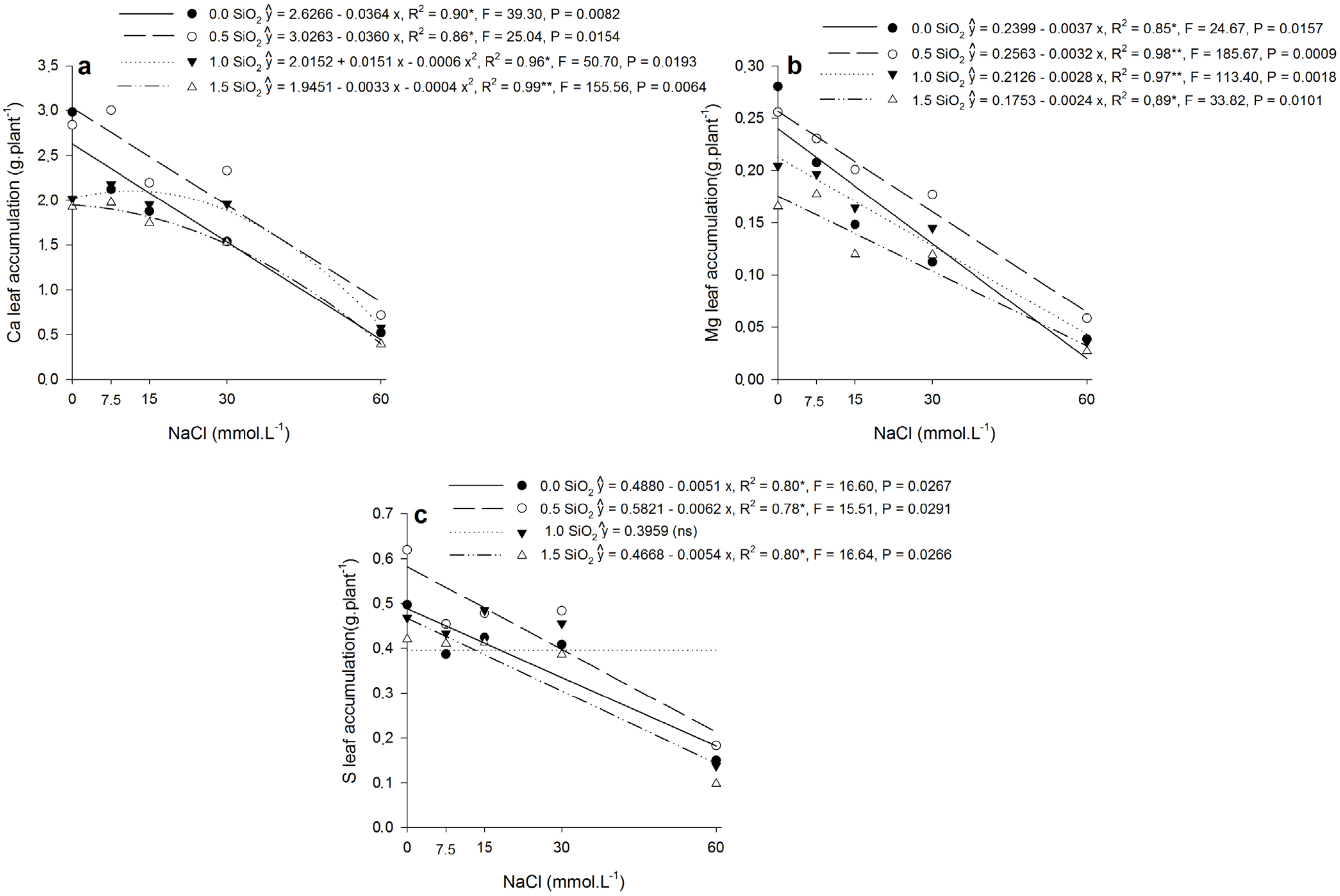


**Figure 5**. Ca (a), Mg (b) e S (c) leaf accumulation of yellow passion fruit as function of NaCl and $SiO_2$ levels supply in the nutrient solution. ** $p<0.01$; * $p<0.05$; ns - $p>0.05$.

The reduction of $Ca^{2+}$ uptake in response to salinity is due to inhibition of $Ca^{2+}$ movement in the root apoplast by competition for non-selective cation channels. High levels of $Na^{+}$ also reduce the $Ca^{2+}$ active transport from xylem endoderm (MARSCHNER, 2012). High $Na^{+}$ concentration can displace $Ca^{2+}$ from the plasma membrane, changing its permeability, which can be detected by $K^{+}$ exit from the cells (TAIZ et al., 2017).

For all applied $SiO_2$ concentrations, Mg leaf accumulation reduced with an increase of NaCl supply (Figure 5b). Plants cultivated with 60 mmol $L^{-1}$ of NaCl had 0.04, 0.06, 0.04, and 0.03 g $plant^{-1}$ showed lower Mg leaf accumulation at concentrations 0, 0.5, 1.0, and 1.5 mmol $L^{-1}$ of $SiO_2$, respectively. These observations are similar to reports by Hu and Schmidhalter (2001), who observed that the decrease of Mg accumulation may be related to the ionic competition with Na. Mg is mobile in the phloem and, under very low levels, symptoms of interveinal chlorosis appears, mainly in older leaves, indicating chlorophyll non-formation (TAIZ et al., 2017). In the solution with 60 mmol $L^{-1}$ of NaCl, these symptoms were observed due to the competitive inhibition between Na and Mg for the same absorption sites. Miranda et al. (2010) also observed a linear reduction of Mg accumulation in dwarf cashew leaves, sensitive to salinity with NaCl, in the absence and presence of 0.5 mmol $L^{-1}$ of $SiO_2$; however, the application of 1.0 mmol $L^{-1}$ of $SiO_2$ increased Mg accumulation up to 63.9 mmol $L^{-1}$ of NaCl.

The increase of the NaCl supply, at concentrations 0, 0.5, and 1.5 mmol $L^{-1}$ of $SiO_2$ decreased S leaf accumulation (Figure 5c). The maximum S leaf accumulation was 0.62 g $plant^{-1}$ with an application of 0.5 mmol $L^{-1}$ of $SiO_2$ in the absence of NaCl. Because of its valency, $Cl^{-}$ is highly mobile in plants and can have acropetal and basipetal translocation. It is more rapidly absorbed than $SO_4^{2-}$, which is transported only in an acropetally direction (KLEINHENZ, 1999; WHITE; BROADLEY, 2001). Therefore, high Cl concentrations in the nutritive solution, due to the application of higher NaCl concentrations, may have favored greater $Cl^{-}$ absorption to the detriment of S absorption. In yellow passion fruit plants, no differences were observed in S leaf concentration and decreases of S absorption were lower in the stem and higher in the roots (CRUZ et al., 2006). Miranda et al. (2010) obtained contrasting results and reported an increasing S leaf accumulation of sensitive plants of *Anacardium occidentale*, submitted to the solution with 0.5 mmol $L^{-1}$ of $SiO_2$ up to the application of 58.6 mmol $L^{-1}$ of NaCl.

## Conclusions

The growth of yellow passion fruit is inhibited by saline stress in a nutritive solution. However, increased $SiO_2$ supply has a mitigating effect at concentrations up to 30 mmol $L^{-1}$ NaCl in the solution. The application of 0.5 mmol $L^{-1}$ of $SiO_2$ reduces the deleterious effects of salinity on the absorption of all macronutrients by yellow passion fruit cultivated in a nutritive solution.

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