APPLICATION OF TWO LEVELS OF CALCIUM NITRATE ON SAP NUTRIENTS, GROWTH AND YIELD OF PERSIAN CUCUMBER †

[APLICACIÓN DE DOS NIVELES DE NITRATO DE CALCIO SOBRE LOS NUTRIENTES DE LA SAVIA, CRECIMIENTO Y RENDIMIENTO DE PEPINO PERSA]

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SUMMARY

Background: Calcium nitrate is a widely used fertilizer in the preparation of nutrient solutions. However, there is still a need to determine the effects of different levels of calcium nitrate on the Persian cucumber crop to optimize fertilization practices and improve crop yield. **Objective:** To determine the effects of two levels of calcium nitrate in the nutrient solution on the growth, yield, and nutrient content of two Persian cucumber hybrids (Bereket and Cruz). **Methodology:** The experiment was carried out in a completely randomized design in a factorial arrangement (two hybrids and two nutrient solutions) under greenhouse conditions. **Results:** The nutrient solution with 11 meq L^{-1} of calcium nitrate increased the concentration of nitrate and calcium in the petiole sap of the Cruz hybrid in the flowering stage; however, the yield of both hybrids decreased. On the other hand, the nutrient solution with 9 meq L^{-1} of calcium nitrate increased the number of fruits of both hybrids and the yield per plant of the Cruz hybrid. **Implications:** The Cruz hybrid showed to be more efficient in calcium uptake than the Bereket hybrid, which is interesting since it could require less calcium application without affecting yield. However, other studies are necessary to expand this information. **Conclusion:** The nutrient solution containing 9 meq L^{-1} of calcium nitrate showed a significant increase in the number of fruits per plant for both the Cruz and Bereket hybrids. This highlights the importance of appropriate calcium nitrate supplementation in the nutrient solution, as it enhances the production of hydroponically grown Persian cucumbers.
Keywords: *Cucumis sativus* L.; cucumber in greenhouse; hydroponic cucumber; cucumber crop nutrition.

RESUMEN

Antecedentes: El nitrato de calcio es un fertilizante ampliamente utilizado en la preparación de soluciones nutritivas. Sin embargo, aún existe la necesidad de determinar los efectos de diferentes niveles de nitrato de calcio en el cultivo de pepino persa que permita optimizar las prácticas de fertilización y mejorar el rendimiento del cultivo. **Objetivo:** Determinar los efectos de dos niveles de nitrato de calcio en la solución nutritiva sobre el crecimiento, rendimiento y contenido de nutrientes de dos híbridos de pepino persa (Bereket y Cruz). **Metodología:** El experimento se realizó en un diseño completamente al azar en arreglo factorial (dos híbridos y dos soluciones nutritivas) en condiciones de invernadero. **Resultados:** La solución nutritiva con 11 meq L^{-1} de nitrato de calcio incrementó la concentración de nitrato y calcio en la savia del peciolo del híbrido Cruz en la etapa de floración, sin embargo, disminuyó el rendimiento de ambos híbridos. Por otro lado, la solución nutritiva con 9 meq L^{-1} de nitrato de calcio incrementó el número de frutos de ambos híbridos y el rendimiento por planta del híbrido Cruz. **Implicaciones:** El híbrido Cruz mostró ser más eficiente en la absorción de calcio que el híbrido Bereket, lo que resulta interesante ya que podría requerir menos aplicación de calcio sin afectar el rendimiento, sin embargo, es necesario de otros estudios para ampliar esta información. **Conclusión:** La solución nutritiva con 9 meq L^{-1} de nitrato de calcio mostró un aumento significativo en el número de frutos por planta tanto para el híbrido Cruz como para el híbrido Bereket. Esto destaca la importancia de la suplementación adecuada con nitrato de calcio en la solución nutritiva, ya que mejora la producción de pepino persa cultivado hidropónicamente.
Palabras claves: *Cucumis sativus* L.; pepino en invernadero; pepino hidropónico; nutrición del cultivo de pepino.

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INTRODUCTION

Cucumber (*Cucumis sativus*) is a highly demanded vegetable for human consumption due to its rich source of potassium, calcium, and vitamin A (Manjunatha and Anurag, 2014). Cucumbers are usually classified according to the size of the fruit, so there are long, medium, and short cucumbers (Guan *et al.*, 2019). The Persian cucumber, also called mini cucumber or Beit alpha is a short cucumber. The fruits are parthenocarpic (seedless) and the skin is thin (Sánchez *et al.*, 2021). In Mexico, the production of Persian cucumbers began in 2015 under greenhouse and shade house conditions. Between 2015 and 2020, an average of 582 ha of Persian cucumber was sown with an average yield of 106 t ha^{-1}, which was mainly exported fresh to the United States (SIAP, 2020). The Persian cucumber can be more productive than the American slicer or European-type cucumber because it produces multiple fruits in each node of the plant (Guan *et al.*, 2019).

One of the most widely used hydroponic techniques to produce cucumber in greenhouses is the drip irrigation system using substrates such as peat, coconut fiber, rockwool, sand, and tezontle, among others (Rodríguez-Delfín, 2012). In this hydroponic system, macro and micronutrients are supplied to the plants through the nutrient solution, which must contain the optimal concentrations of nutrients for the growth and development of the crop (Sambo *et al.*, 2019). When nutrient concentrations in the nutrient solution are high, salinity problems (osmotic stress), nutrient imbalances or toxicity can occur. However, if concentrations are low or inadequate (Savvas and Adamidis, 1999), it can cause deficiencies that can reduce or limit crop growth and yield. There are several formulations of nutrient solutions available for the hydroponic cultivation of cucumbers, including those proposed by Hoagland, Resh, and Steiner, among others (Resh, 2013; Li and Cheng, 2015; Ramírez-Pérez *et al.*, 2018). However, it is worth noting that most of these nutrient solutions have been primarily applied to American slicer-type cucumbers (Ramírez-Pérez *et al.*, 2018). In contrast, information on nutrient solutions for Persian cucumber is scarce (Shaw *et al.*, 2004; Alejo-Santiago *et al.*, 2021). The composition of the nutrient solutions for the Persian cucumber is important because it produces seedless fruits, and the nutrient demand could vary with respect to the cucumbers that do produce seeds. Furthermore, the existing genetic variability between cultivars of Persian cucumber must also be considered (Guan *et al.*, 2019; Maeda and Ahn, 2021).

As with most crops, nitrogen is one of the most important macronutrients for cucumber plants and can be supplied in the form of nitrate or ammonium (Roosta *et al.*, 2009). Nitrogen is an essential component for plants as it is part of nucleotides, amino acids, proteins, and chlorophyll (Nunes-Nesi *et al.*, 2010). Calcium, on the other hand, is another essential macronutrient that is a structural component of cell walls and membranes and a second intercellular messenger (Thor, 2019). The nitrate/calcium ratio is an important consideration in the composition of the nutrient solution, as an adequate supply of calcium has been shown to improve the efficiency of nitrate uptake and transport (Xing *et al.*, 2021, 2022). Similarly, calcium uptake is enhanced when nitrogen is supplied in the nitrate form compared to the ammonium form (Marti and Mills, 1991). Therefore, the present study aimed to evaluate two levels of calcium nitrate in the nutrient solution on the concentration in the petiole sap, growth and yield of two Persian cucumber hybrids.

MATERIALS AND METHODS

Experimental conditions and treatments

The experiment was conducted out in a greenhouse (8.0 m wide, 31.5 m long, 4.0 m high, polyethylene cover) at the University of Papaloapan in Loma Bonita, Oaxaca (95º 53' W and 18º 06' N) at 30 masl. The temperature and relative humidity inside the greenhouse during the experiment are shown in Figure 1. The experiment was conducted in a completely randomized design in a factorial arrangement (2x2) with three replicates. Each experimental unit consisted of six plants. The first factor consisted of two Persian cucumber hybrids (Bereket and Cruz from the Hazera Seeds®) and the second factor consisted of two nutrient solutions (NS1 and NS2; Table 1). The seeds of the Persian cucumber hybrids were sown on November 2, 2020, in 98-cavity polystyrene trays with peat moss as a substrate. The seedlings were transplanted 19 days after sowing into black 7.5-L polyethylene pots filled with a mixture of coconut fiber and tezontle substrate in a 1:1 (v/v) ratio. The pots were placed in four double rows and each double row was divided into three experimental units (six plants per experimental unit with 0.3 m between plants) with a separation of 1.2 m between the double row and the experimental unit. The plants were irrigated with a drip irrigation system with emitters of 1 L per hour in each pot. The plants were pruned to a single stem by removing the axillary shoots and supported by the greenhouse structure with a plastic ring and raffia ties.

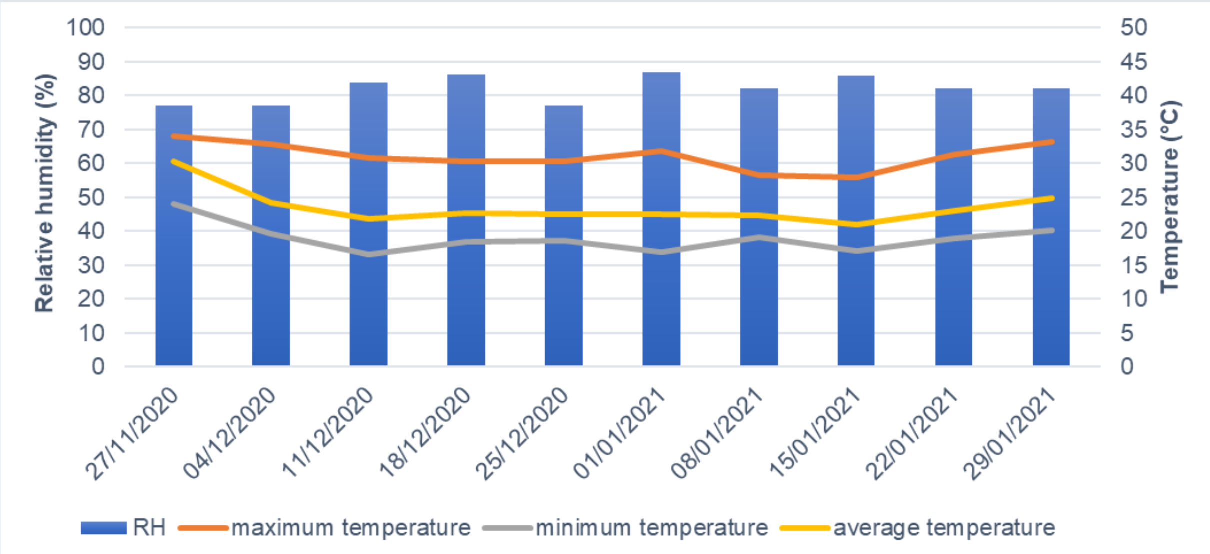

Figure 1. Temperature and relative humidity (RH) inside the greenhouse during the experiment.

Nutrient solutions

The two nutrient solutions evaluated in the experiment are based on Shaw *et al.* (2004) as shown in Tables 1 and 2, which contain 11 and 9 milliequivalents of calcium nitrate (NS1 and NS2, respectively). Ultrasol Micromix® (Fe-EDTA 7.5%, Mn-EDTA 3.7%, B 0.4%, Zn-EDTA 0.6%, Cu-EDTA 0.3% and Mo 0.2%) was used as the source of micronutrients. The pH was adjusted with sulfuric acid in a range of 5.8-6.2. Each nutrient solution was applied at a different time to avoid mixing the drainage of both nutrient solutions. The irrigation frequency was three irrigations per day for 30 minutes each for each nutrient solution. The concentrations of both nutrient solutions were applied according to the phenological stage of the cucumber, as shown in Tables 1 and 2.

Ion content and pH in the sap

To measure the content of ions (NO_3^-, K^+ y Ca^{2+}) and pH of the petiole sap, two fully expanded young leaves were collected from plants in each experimental unit between 09:00 and 11:00 a.m. The petiole of each leaf was cut into 0.5 cm fractions, and the sap was immediately extracted using a hydraulic press according to the methodology described by Cadahía-López (2008). The undiluted sap was then directly applied to the electrodes of the LAQUAtwin® portable device (Horiba Kyoto, JP), which had been previously calibrated with the manufacturer's solutions. Two measurements were taken during the experiment, at the flowering and fruiting stages, and each of these parameters was measured in triplicate.

Table 1. Nutrient solutions with different concentrations of nitrate and calcium (meq L^{-1}).

Nutrient Solution	NO_3^-	PO_4^-	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}
NS1: transplant	10.0	1.0	3.0	4.0	8.0	2.0
NS2: transplant	9.0	1.0	3.0	4.0	7.0	2.0
NS1: flowering-harvest	14.5	1.4	4.4	5.3	11	4.1
NS2: flowering-harvest	13.0	1.4	4.4	5.3	9	4.1

NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca.

Table 2. Fertilizers used to prepare nutrient solutions (g L^{-1}).

Fertilizer Sources	NS1 trasplant	NS2 trasplant	NS1 flowering-harvest	NS2 flowering-harvest
$Ca(NO_3)_2.4H_2O$	0.952	0.810	1.270	1.080
$MgSO_4.7H_2O$	0.230	0.230	0.355	0.355
KNO_3	0.187	0.187	0.250	0.250
$Mg(NO_3)_2.6H_2O$	-	-	0.160	0.160
K_2SO_4	0.097	0.097	0.130	0.130
KH_2PO_4	0.138	0.138	0.185	0.185
Micronutrients	0.037	0.037	0.050	0.050

NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca.

Growth

For each treatment, the height of the plant was measured from the base of the stem to the apex, the diameter of the stem base was measured, and the number of leaves per plant was counted. To determine the leaf area of each treatment, the leaf length was measured from the base to the apex, while the leaf width was measured from one end to the other from the center of the leaf. Leaf area (LA) was then calculated using the linear regression equation established by Blanco and Folegatti (2003). These measurements were made out in triplicate at the flowering and fruiting stages of the Persian cucumber.

Biomass and yield components

At 70 days after transplanting, the stems and leaves of the six plants from each experimental unit were placed in paper bags and dried in a drying oven at 80 °C for 72 h. Once fully dried, they were weighed with an electronic balance (Rhino® model BAPRE-3). Fruit harvesting began 46 days after transplanting, for a total of five harvests at 3-4 day intervals. At each harvest, fruit length was measured with a tape measure, fruit diameter was measured with a digital caliper, fruit weight was measured with an electronic scale, and the number of fruits harvested per plant from each treatment was determined. To determine the yield per plant of each treatment, the weight of the fruit from the five harvests made during the experiment was added.

Analysis of data

Three replicates per treatment were used to analyze the variables evaluated. Two-way analysis of variance and Fisher means test ($p \leq 0.05$) were performed using the InfoStat software version 2020. In addition, Pearson correlation analysis and principal components analysis were applied to the variables measured in the flowering and fruiting stages.

RESULTS

Nutrient content and pH in the petiole sap

Persian cucumber hybrids and nutrient solutions showed significant differences ($p \leq 0.05$) in nutrient content and sap pH (Table 3). Among the hybrids, the Cruz hybrid showed higher calcium content in the petiole sap at the flowering and fruiting stages and higher nitrate content at the flowering stage. In contrast, the Bereket hybrid showed higher potassium content at the flowering stage. Among the nutrient solutions, nutrient solution 1 (NS1) increased the nitrate content in the petiole sap at the flowering and fruiting stages, and the calcium content at the flowering stage. However, nutrient solution 2 (NS2) increased the potassium content of the petiole sap at the flowering stage (Table 3). The interaction between the nutrient solutions and the hybrids showed significant differences ($p \leq 0.05$) in the nutrient content and the pH of the petiole sap (Figure 2). The application of NS1 during the flowering period increased the nitrate and calcium content of the petiole of the Cruz hybrid compared to NS2, while during the fruiting period only the nitrate content increased (Figure 2A, 2B). In contrast, NS2 applied during the flowering period increased the potassium content of the petiole sap of both hybrids (Bereket and Cruz) compared to NS1, while no significant differences were observed during the fruiting period (Figure 2C). NS1 increased the pH of the sap of the Cruz hybrid during the flowering stage compared to NS2, while no significant differences were observed during the fruiting period (Figure 2D).

Growth

Persian cucumber hybrids and nutrient solutions showed significant differences ($p \leq 0.05$) in growth variables (Table 4). Among the hybrids, the Bereket hybrid showed a higher height and number of leaves in the fruiting period. Among the nutrient solutions, nutrient solution 2 increased the stem diameter in the

Table 3. Independent effects of Persian cucumber hybrids and nutrient solutions on sap nutrient content and pH.

	NO_3^- (mg L^{-1})		K^+ (mg L^{-1})		Ca^{2+} (mg L^{-1})		pH	
	FL	FR	FL	FR	FL	FR	FL	FR
Hybrids								
Bereket	2416.67 b	373.33	4000.00 a	3550.00	114.00 b	32.00 b	6.27	5.77
Cruz	3800.00 a	383.33	3566.67 b	3600.00	196.67 a	46.17 a	6.35	5.85
Nutrient Solutions								
NS1	3500.00 a	408.33 a	3533.33 b	3716.67	191.67 a	39.50	6.35	5.83
NS2	2716.67 b	348.33 b	4033.33 a	3433.33	119.00 b	38.67	6.27	5.78

FL: Flowering; FR: Fruiting; NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca. Different lowercase letters between columns indicate a significant difference according to the Fisher LSD test ($p \leq 0.05$).

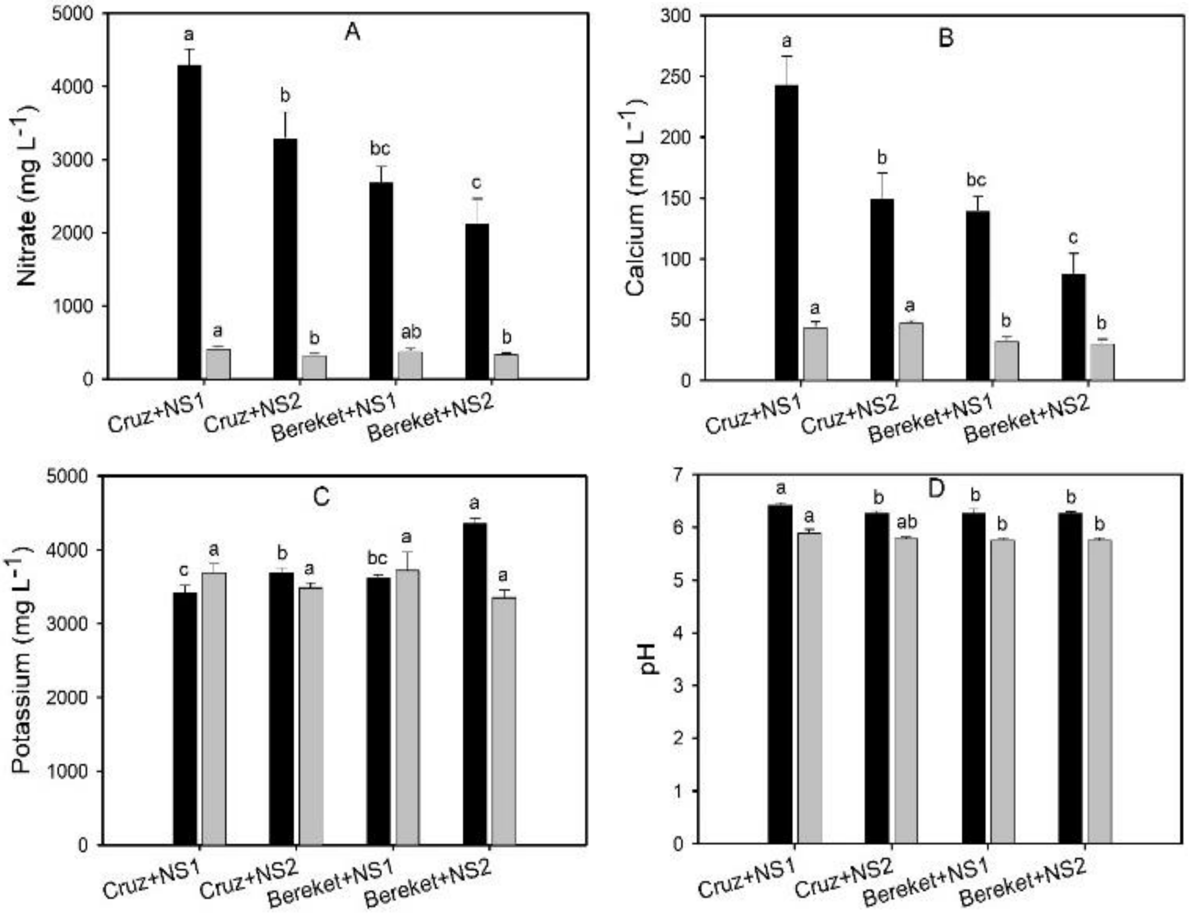

Figure 2. Effect of the interaction of nutrient solutions (NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca) on nitrate ions (A), calcium (B), potassium (C) and pH (D) of the petiole sap of hybrid Persian cucumbers (Cruz and Bereket) in the flowering (black bars) and fruiting (gray bars) period. Different lowercase letters between bars of the same color indicate a significant difference according to the Fisher LSD test ($p \leq 0.05$).

flowering and fruiting stages, and the number of leaves in the flowering stage. In contrast, NS1 increased plant height in the flowering stage (Table 4). The interaction between the nutrient solutions and the hybrids showed significant differences ($p \leq 0.05$) in the growth variables (Figure 3). NS1 significantly increased the height and leaf area of the Cruz hybrid during the flowering period (Figure 3A, 3C). In contrast, NS2 increased the number of leaves and the stem diameter of the Bereket hybrid during the flowering and fruiting periods (Figure 3B, 3D), but only the number of leaves of the Cruz hybrid during the flowering period (Figure 3B).

Table 4. Independent effects of nutrient solutions and Persian cucumber hybrids on growth.

	Plant height (cm)		Stem diameter (mm)		Number of leaves		Leaf area (cm^2)	
	FL	FR	FL	FR	FL	FR	FL	FR
Hybrids								
Bereket	87.57	227.95 a	4.97	5.73	11.77	16.77 a	487.68	513.45
Cruz	87.15	135.03 b	5.20	5.83	11.67	12.52 b	533.47	402.37
Nutrient Solutions								
NS1	91.33 a	187.78	4.55 b	5.42 b	11.08 b	14.42	542.52 a	451.73
NS2	83.38 b	175.20	5.62 a	6.15 a	12.35 a	14.87	478.63 b	464.08

FL: Flowering; FR: Fruiting; NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca. Different lowercase letters between columns indicate a significant difference according to the Fisher LSD test ($p \leq 0.05$).

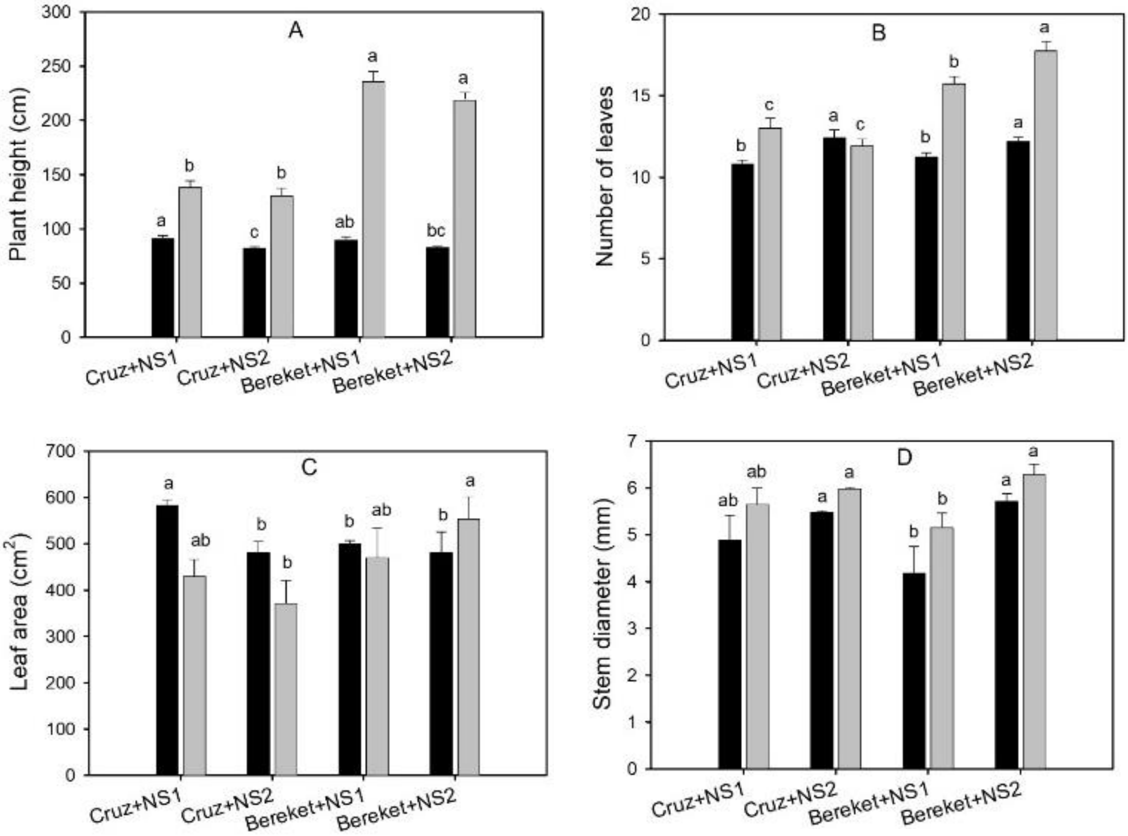

Figure 3. Effect of the interaction of nutrient solutions (NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca) on the height (A), number of leaves (B), leaf area (C) and stem diameter (D) of the two Persian cucumber cultivars (Cruz and Bereket) in the flowering (black bars) and fruiting (gray bars) period. Different lowercase letters between bars of the same color indicate a significant difference according to the Fisher LSD test ($p \leq 0.05$).

Dry biomass (stem–leaf) and yield components

The Persian cucumber hybrids and the nutrient solutions showed significant differences ($p \leq 0.05$) in the accumulation of dry biomass and yield components (Table 5). Among the hybrids, the Bereket hybrid showed higher dry biomass of stem and leaves, diameter, length, and fruit weight. Among the nutrient solutions, NS2 increased the number of fruits and fruit yield per plant, while NS1 increased the fruit weight (Table 5). The interaction between the nutrient solutions and the hybrids showed significant differences ($p \leq 0.05$) in the accumulation of dry biomass and the variables of yield components (Figure 4). The Bereket hybrid showed higher dry biomass in both nutrient solutions than the Cruz hybrid (Figure 4A). NS1 significantly increased the fruit length of the Bereket hybrid compared to the Cruz hybrid (Figure 4B), while NS2 increased the fruit diameter of the Bereket hybrid (Figure 4C). NS1 increased the average fruit weight of both hybrids compared to NS2 (Figure 4D). However, NS2 significantly increased the number of fruits of both hybrids (Figure 4E) and the yield of the Cruz hybrid compared to NS1 (Figure 4F).

Table 5. Independent effects of nutrient solutions and Persian cucumber hybrids on dry biomass (stem-leaf) and yield components.

	Dry biomass of stem and leaves (g)	Number of fruits per plant	Average fruit diameter (mm)	Average fruit length (cm)	Average fruit weight (g)	Yield per plant (g)
Hybrids						
Bereket	271.17 a	9.14	47.13 a	17.79 a	398.34 a	3622.33
Cruz	120.50 b	9.28	44.86 b	15.89 b	363.79 b	3343.79
Nutrient Solutions						
NS1	192.83	7.84 b	46.13	17.28	389.90 a	3065.82 b
NS2	198.83	10.58 a	45.86	16.40	372.23 b	3900.30 a

FL: Flowering; FR: Fruiting; NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca. Different lowercase letters between columns indicate a significant difference according to the Fisher LSD test ($p \leq 0.05$).

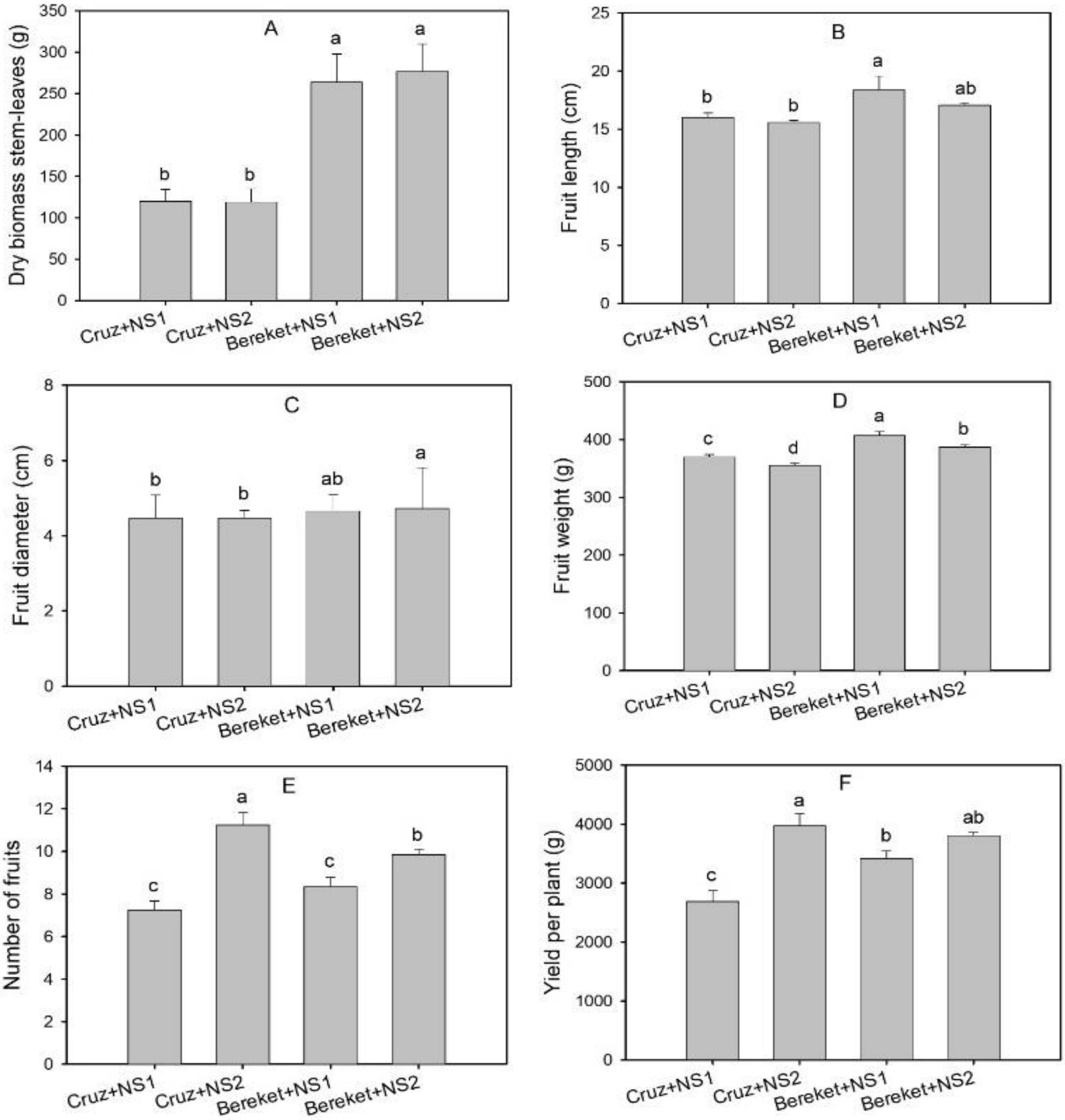

Figure 4. Effect of the interaction of nutrient solutions (NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca) on stem and leaf dry biomass (A), fruit length (B), fruit diameter (C), fruit weight (D), number of fruits per plant (E) and yield per plant (F) of the two Persian cucumber cultivars (Cruz and Bereket). Different lowercase letters between bars indicate a significant difference according to the Fisher LSD test ($p \leq 0.05$).

Pearson correlation analysis and principal components

The Pearson correlation analysis showed different patterns of significant correlations between the parameters measured in the flowering and fruiting stages (Figure 5A). Sap nitrate was positively correlated with sap calcium and sap pH, and negatively correlated with leaf number, plant height, and stem diameter. Sap calcium was positively correlated with sap pH and leaf area; and negatively correlated with leaf number, plant height, and stem diameter. In addition, sap pH was negatively correlated with plant height and leaf number, while plant height was positively correlated with the leaf number (Figure 5A).

Principal component analysis (PCA) showed that PCA 1 and PCA 2 explained 85% of the variability in the data (Figure 5B). The PCA showed that the NS1 applied to the Cruz hybrid was associated with sap nitrate, calcium, and pH. In contrast, NS2 applied to both hybrids was associated with stem diameter. On the other hand, the Bereket hybrid irrigated with both nutrient solutions was associated with plant height, number of leaves, leaf area, and sap potassium (Figure 5B).

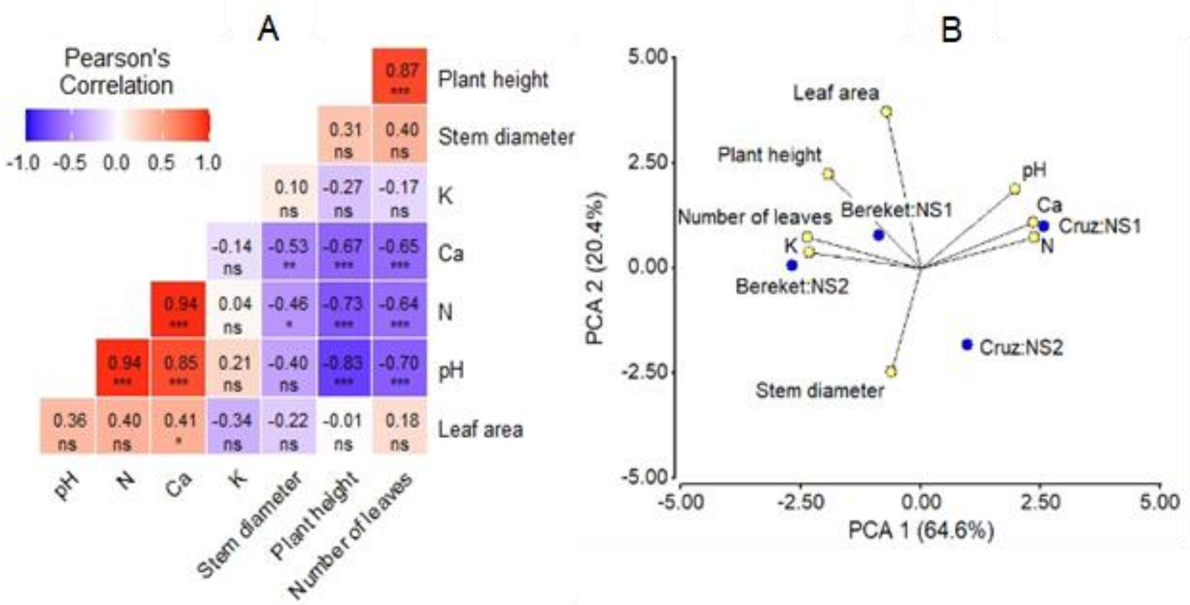

Figure 5. Pearson correlation heatmap (**A**) and principal component analysis (**B**). In heatmap, ns p>0.05; * p<0.05; ** p<0.01 and *** p<0.001. NS1: Nutrient solution high in N and Ca. NS2: Nutrient solution low in N and Ca.

DISCUSSION

In this study, we showed that NS1, which contains more calcium nitrate, increased nitrate, calcium, and pH in the petiole sap of the Cruz hybrid at the flowering stage. This result was confirmed by the principal components analysis, as shown in Figure 5. Previous studies are similar to our results, showing that the application of a high rate of nitrogen or calcium is reflected in a greater accumulation of these elements in the dry biomass of the cucumber crop (Ruiz and Romero, 1999; Kaya and Higgs, 2002; Kaya *et al.*, 2003; Al-Jaloud *et al.*, 2006; Beigi *et al.*, 2011). Furthermore, in this study, nitrate, calcium, and sap pH showed a significant positive correlation (Figure 5). Previous studies have shown that an adequate supply of calcium improves the efficiency of nitrate uptake and transport by increasing the activities of N-metabolizing enzymes and the net photosynthetic rate of the plant (Xing *et al.*, 2021, 2022). Similarly, a good supply of nitrate has been shown to improve calcium uptake (Marti and Mills, 1991). This is because calcium as a second messenger regulates the activities of calcium-dependent protein kinases (CPKs) and activates nitrate signaling (Wang *et al.*, 2020). Therefore, calcium plays an important role in the regulation of nitrate transporters and signaling in the primary response to nitrate (Ma *et al.*, 2015; Liu *et al.*, 2020; Adavi and Sathee, 2021). Similarly, cellular pH has been shown to directly regulate nitrate transport activity, which means that an increase in nitrate concentration causes the pH to rise (Jia and Davies, 2007). In addition, pH and cellular calcium interact together and function as signaling molecules in plants (Felle, 2001; Kader and Lindberg, 2010). On the other hand, in this study, we showed that the NS2, which contains less calcium nitrate, increased the potassium content of the petiole sap of both hybrids at the flowering stage. This was probably due to the synergy between nitrogen and potassium since plant nitrogen concentrations affect potassium uptake and plant potassium concentrations affect nitrate uptake (Reid *et al.*, 2016). Among the hybrids, the Cruz hybrid was shown to have a higher calcium uptake capacity than the Bereket hybrid, which was reflected in the increased calcium concentration in the petiole sap during the flowering and fruiting periods. This is consistent with the study of Arshad *et al.* (2012), who reported that under conditions of low calcium supply, certain wheat genotypes can absorb and utilize better calcium than other genotypes. In hydroponic cucumber, this strategy could be of interest, since by using genotypes efficient genotypes in calcium absorption, the calcium concentration in the nutrient solution can probably be reduced without affecting the yield, but future studies are needed to clarify this hypothesis.

Regarding the growth and yield variables, NS1 decreased the number of fruits and yield of both hybrids and decreased the number of leaves and stem diameter of the Bereket hybrid. On the other hand, the NS2 was associated with an increase in stem diameter and the number of fruits of both hybrids and an increase in the yield of the Cruz hybrid. Previous studies have shown that cucumber yield decreases with high concentrations of nitrogen in the nutrient solution (Ruiz and Romero, 1999; Al-Jaloud *et al.*, 2006; Beigi *et al.*, 2011), which is consistent with the results reported here. Similarly, in *Capsicum annuum* it has been shown that the high application of nitrate and calcium reduces plant growth. This reduction is probably due to the increased salinity of the nutrient solution and the higher osmotic potential of the culture medium (Guzmán and Sánchez, 2003). Therefore, it is important to maintain a good balance of nitrate and calcium in the nutrient solution to improve plant growth and yield (Guzmán and Sánchez, 2003; Xing *et al.*, 2022), as it has been shown that a good supply of nitrogen increases crop yield by improving the capacity of the source to the sink (Li *et al.*, 2016). The source-sink relationship determines crop yield and is largely regulated by water and nutrients (Li *et al.*, 2016). In this study, NS2 had a better balance of nitrate and calcium, which was reflected in a higher yield of Persian cucumber. It was also shown here that the Bereket hybrid had greater height, number of leaves, dry biomass (stem and leaves), and larger and heavier fruits than the Cruz hybrid, but this genetic difference was not reflected in the increase in yield. The Cruz hybrid proved to be a good genotype despite having lower growth and biomass than the Bereket hybrid.

CONCLUSIONS

The nutrient solution with the highest concentration of calcium nitrate increased the concentration of these elements in the petiole sap of the Cruz hybrid at the flowering stage. However, this nutrient solution negatively affected the yield of Cruz and Bereket hybrids. On the other hand, the nutrient solution with a lower concentration of calcium nitrate increased the number of fruits per plant of both hybrids and increased the yield of the Cruz hybrid. In addition, the Cruz hybrid had a higher calcium uptake capacity than the Bereket hybrid, which was reflected in a higher calcium concentration in the petiole sap at the flowering and fruiting stages. Therefore, an adequate supply of nitrate calcium in the nutrient solution improves hydroponic Persian cucumber production.

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Author contributions statement (CRediT). I. Chareo-Benítez– Investigation, data curation and writing – original draft. **J.A. Yam-Tzec**– methodology, resources and writing – review & editing**.** A.R. Ramírez-Seañez– visualization, resources and writing – review & editing. **J.O. Gutiérrez-Hernández**– investigation and data curation. **H. Hernández-Hernández**– conceptualization, supervision, formal analysis and writing – review & editing.

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