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Article

Cucumber nutrition using chelated liquid fertilizers

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Abstract

Cucumber (*Cucumis sativus* L.) is a very important crop in Mexico and requires large amounts of nutrients for its development. As a result, synthetic fertilizers are used intensively. However, plants assimilate only a small fraction of the nutrients they contain, which increases environmental pollution. An alternative is using chelates in fertilizers. Therefore, this study evaluated the effects of liquid chelated calcium, potassium, and magnesium fertilizers on yield and fruit quality in cucumber crops, applied via fertigation under shade-net conditions in Culiacán, Sinaloa, during the autumn-winter 2021-2022 cycle. The experimental design consisted of homogenous plot pairs with two treatments, one with chelated fertilizers and a control with traditional fertilization applied by the cooperating producer, with five replications. The number of plants evaluated was determined by simple random sampling, yielding 113 plants per treatment, which were randomly selected in two steps: first, rows were selected, then the plants within each row. The response variables were fruit quality and yield. It was found that chelated fertilizers increased potassium, calcium and magnesium concentrations in stems, leaves and fruits, resulting in fruits with greater firmness and length and consequently, higher yield. Therefore, it is concluded that the application of chelated Ca, K and Mg makes fertilizer use more efficient and increases cucumber yield.

Keywords:

chelates, degrees brix, fruit firmness, nutrient translocation.



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Introduction

Cucumber (*Cucumis sativus* L.) is a crop of great importance in Mexico (FAOSTAT, 2021). This vegetable is fast-growing and developing, so it demands a large amount of nutrients (Barraza, 2018; Valenzuela, 2025), which are supplied through chemical and synthetic fertilizers, but plants do not assimilate much of them, generating environmental pollution (Chittora *et al*., 2023). In addition, several fertilizers are non-renewable (Babcock-Jackson *et al*., 2023) and are in high demand in intensive agriculture.

Fertilizers must be used efficiently, which requires: a) adequate genetic material (Rueda *et al*., 2025); b) altering the physicochemical characteristics of the soil and of the interaction among the nutrients applied (Yang *et al*., 2024); and c) making the transport of nutrients within the plant more efficient using chelates (Fu *et al*., 2026). Nonetheless, they can also chelate some macronutrients, such as calcium, magnesium and potassium.

Based on their biochemical behavior and physiological function, Ca, Mg and K are part of a group of nutrients that can be chelated and are readily absorbed as ions from the soil solution (Mengel and Kirkby, 2000). The present research focuses on this group of nutrients. This is because these ions, being encapsulated by the chelating molecule, do not have adverse chemical reactions with other elements in the soil, such as phosphorus, and are more easily transported (Manik *et al*., 2023), generating synergies with organic matter and making fertilizer use more efficient (Fu *et al*., 2026).

The most common sources of Ca, Mg and K are highly soluble and can be lost more easily than chelated fertilizers; for this reason, if the latter are chosen, fertilization may be more efficient, as this enables them to be available for longer in the plant (Areche *et al*., 2023). Therefore, the present research aimed to evaluate the efficiency of chelates in the assimilation of K, Ca and Mg in cucumber plants and their effect on fruit quality and crop yield, under the hypothesis that chelated fertilizers will modify the concentrations of K, Ca and Mg in plant organs and influence crop yield.

Materials and methods

Study area and trial establishment

The study was conducted in Culiacán, Sinaloa, during the autumn-winter cycle of 2021-2022, with a cooperating producer at the agricultural company El Porvenir, located along the Villa Benito Juárez-Navolato highway, at coordinates 24.654° north latitude, 107.506° west longitude and an altitude of 20 m. The site has a semi-arid, very warm climate with summer rainfall. The soil is silty loam according to the USDA texture triangle (Moreno-Maroto and Alonso-Azcárate, 2022).

The trial was established under shade-net conditions using an experimental design with homogeneous plot pairs, two treatments and five replications. Each replication consisted of five furrows with two plant rows. The experimental unit was 10 m long and contained approximately 325 plants.

The replications were systematically distributed every 20 m, starting 10 m from the furrow edge, with 5 m between replications. Each treatment was separated by two furrows within a 5 ha house. One treatment was the application of conventional synthetic fertilizers (CFT) used by the cooperating producer.

Treatment two consisted of the same fertilization, supplemented with chelated liquid fertilizers (ChFT). A white anti-aphid shade net with an opening size of 200 microns, 20% shade and a density of 130 g m was used.

The planting beds were mulched with black plastic. The plant material used was the American slicer-type cucumber hybrid named ‘Zeus’ from the commercial house ‘Semillas Fitó.’ The plants were placed in double rows in a zigzag pattern, 30 cm apart, yielding approximately 40 000 plants ha^{-1}. Two fertilization treatments were evaluated: T1) chelated fertilizers and T2) conventional fertilization (Tables 1 and 2).

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Table 1. Source and dose (kg ha^{-1}) of fertilizers applied at each stage in treatment 1.

Source	First stage	Second stage	Third stage
$CaNO_3$	6	12	12
Chelated calcium	1	2	2.5
KNO_3	4	8	8
KCl	2.5	5	5
Chelated potassium	0.79	1.6	2
$MgSO_4$	7	14	14
Chelated magnesium	0.78	1.6	2
Phosphonitrate	5.7	5.7	5.7
Chelated MicroMix	0.35	0.35	0.3
Phosphoric acid	-	-	0.5
Sulfuric acid	-	-	0.3

Table 2. Source and dose (kg ha^{-1}) of fertilizers applied at each stage in treatment 2.

Source	First stage	Second stage	Third stage
$CaNO_3$	7	14	24
KNO_3	4	8	16
KCl	2.5	5	10
$MgSO_4$	7	14	28
Phosphonitrate	5.7	5.7	5.7
MicroMix	0.3	0.35	0.35

Fertilization was applied in three stages: a) establishment and vegetative development; b) flowering and fruit set; and c) flowering and harvesting. A drip irrigation system was used, placing two tapes per planting bed. Water needs were determined using humidity sensors at depths of 15 and 30 cm, and readings were taken with the Watermark digital meter. When pressure reached 35 kPa, irrigation was applied to bring it down to 15 kPa. This implied daily irrigation throughout the crop cycle.

Sampling design

To determine the sample size per treatment, a preliminary sampling was conducted to estimate the standard deviation. To do this, the height of 100 plants was randomly measured in each house one week after transplantation. Subsequently, the final sample size for each treatment was calculated using the following formula (Cochran, 1998).

$$n \cong \frac{2\left(Z_\alpha + Z_\beta\right)^2 S^2}{d^2}$$

Z_α= 1.96; Z_β= 1.68; S= standard deviation; d= margin of error (7.5%).

With the confidence level and the margin of error established, the sample size of plants to be sampled by treatment was determined and the plants were randomly selected. First, the furrows were defined, and then, in each one, the distance at which the plants would be located in each furrow was randomly determined.

Over six periods, the concentrations of K, Ca and Mg in leaves, fruits and stems were measured. K was determined by ammonium acetate extraction by flame photometry and Ca and Mg were measured by colorimetric determination using an atomic absorption spectrophotometer (Varian SpectrAA 220) (AOAC, 2006).

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The collected data were used to generate absorption curves for these elements. In addition, the concentrations of these nutrients in leaves at three maturity stages-old, intermediate, and young-were evaluated. Quality was also assessed using the variables weight, length, firmness and Brix concentration in cucumber fruits.

The soluble solids content of the cucumber fruits was measured with an ANA Hi96801 digital refractometer; to do so, samples were taken by cutting pieces of the fruit and squeezing them into the refractometer, completely covering the measured surface with cucumber juice. Data was collected across 18 harvest events during the crop production cycle, which lasted 136 days after transplanting.

Statistical analysis

An analysis of variance was conducted on nutrient concentrations by plant organ. The data were previously tested for normality using the Shapiro test (Shapiro and Wilk, 1965) and for homoscedasticity using the Bartlett test (Zar, 2010). The method used to compare the means was Tukey's test (p= 0.05). The XlStat statistical package (Addinsoft, 2023) was used.

To estimate fruit quality, fruits were classified into marketing quality categories. The weight categories were as follows: extra-large= >400 g; large= 300 to 400 g; medium= 200 to 300 g; small= 100 to 200 g. The length categories were as follows: large= >25.5 cm; super select= 24 to 25.5 cm; select= 22 to 24; small= 20 to 22 cm.

To analyze the proportion of categories, the Z-test was applied based on the following formula:

$$Z = \frac{X_i - \mu}{\sigma}$$

Where: Z= Z-statistic; X= category value; μ= population mean; #= standard deviation.

Once the values for each category were obtained, contingency tables were constructed, with the categories on the vertical axis and the two treatments on the horizontal axis. Based on this, the chi-square test was applied to assess the independence of the categories with respect to the treatments, along with Fisher's exact test where the differences were.

The percentage rate of variation (PRV) of the value obtained in the conventional fertilization treatment (CFT) relative to the treatment with chelated fertilizers (ChFT) was also calculated using the following formula:

$$\mathrm{PRV} = \frac{\mathrm{Vch} - \mathrm{Vc}}{\mathrm{Vc}} \times 100$$

Where: PRV= percentage rate of variation; Vch= value obtained in ChFT; Vc= value obtained in CFT.

Results and discussion

Concentration of K, Ca and Mg by organ in cucumber plants

It was observed that ChFT led to higher concentrations of Ca, K and Mg in the evaluated plant organs at the end of the cucumber production cycle. A higher concentration of calcium was found in ChFT at the end of the production cycle, whereas a lower concentration was detected in fruits (Figure 1).

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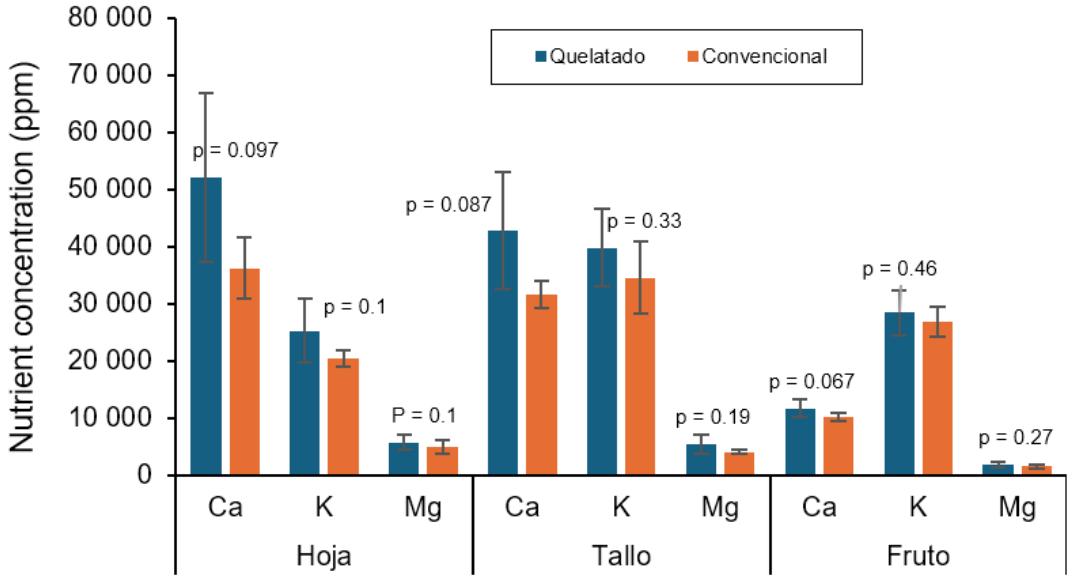
Figure 1. Nutrient concentration by organ ± confidence interval (90%); p= statistical significance.



Regarding Ca, Navarro-León *et al*. (2022) reported that, in their study, levels of this element in leaves (intermediate and young) were also higher in chelated treatments than in non-chelated ones. Similarly, the results obtained align with Souri (2016), who found that applying amino acids and amino acid-chelated fertilizers positively influences growth and leaf mineral concentrations, improving Ca, K and Mg levels.

In the stem, nutrient concentrations were highest in ChFT plants (Figure 1). Because this part of the plant is green, it also contains chlorophyll and the processes of photosynthesis and transpiration occur there; consequently, Ca is transferred directly by the xylem to this organ of the plant (Díaz *et al*., 2007).

With respect to magnesium, this is an element that is part of chlorophyll, which is why it is required (Ishfaq, 2022), and because chelates facilitate its transfer, there is a higher concentration. This aligns with Abbas *et al*. (2020), who found a higher Mg concentration when this element was applied chelated, resulting in greater stem vigor, length and diameter. This also aligns with Souri (2016), who notes that calcium concentration in the stems improved with the application of chelated fertilizers.

For nutrient concentration in cucumber fruits, Ca is the element that differs between the treatments, although with a p= 0. 067 (Figure 1), with the highest concentration in ChFT fruits. In this regard, Navarro-León *et al*. (2022) found a higher Ca concentration in pepper fruits, which is reflected in fruit weight, length, size, firmness, and yield.

The higher concentrations of calcium, potassium, and magnesium in the different organs of the cucumber plant treated with chelated fertilizers are because these minerals had greater mobility and were more easily assimilated, as chelates are very stable and are capable of protecting the metal ion from the environment (Areche *et al*., 2023), avoiding adverse chemical reactions with other elements (Manik *et al*., 2023), generating synergies with organic matter, and making the use of fertilizers more efficient (Fu *et al*., 2026).

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Nutrient absorption by leaf age

When analyzing calcium concentration in leaves classified by age, the two treatments showed similar behavior at the end of the cucumber production cycle, with a higher concentration of this element in ChFT and in old leaves than in intermediate and new leaves (Table 3).

Table 3. Average nutrient concentration (ppm ± confidence interval) by treatment according to the stage of leaf maturity.

Item	Category	Ca	K	Mg
Maturity	L-N	17804 ±7333a	21393 ±2452b	2897 ±1802a
	L-I	36866 ±7333b	12879 ±2452a	4488 ±1802a
	L-O	78811 ±7333c	10886 ±2452a	11678 ±1802b
Treatment	CFT	39395 ±5987a	12952 ±2002a	5347 ±1471a
	ChFT	495923 ±5987b	17153 ±2002b	7361 ±1471a
Maturity-treatment interaction	N-CFT	14398 ±10371a	18904 ±3467bc	2734 ±2548a
	N-ChFT	21208 ±10371ab	23882 ±3467c	3060 ±2548a
	I-CFT	33191 ±10371ab	9943 ±3467a	4277 ±2548ab
	I-ChFT	40542 ±10371b	15815 ±3467ab	4699 ±2548ab
	O-CFT	70594 ±10371c	10009 ±3467a	9031 ±2548bc
	O-ChFT	87028 ±10371c	11762 ±3467ab	14325 ±2548c

L-N= new leaf; L-I= intermediate leaf; L-O= old leaf; CFT= conventional; ChFT= chelated; N-CFT= new leaf with conventional; N-ChFT= new leaf with chelates; I-CFT= intermediate leaf with conventional; I-ChFT= intermediate leaf with chelates; O-CFT= old leaf with conventional; O-ChFT= old leaf with chelates. Means with different letters in the columns indicate significant differences (Tukey, p≤ 0.05).

The higher Ca concentration in old leaves is because one of the characteristics of calcium is its immobility in the phloem, which implies very limited translocation of this element from old leaves to young leaves, shoots and fruits (Marschner, 2012). In contrast, the high Ca concentrations in leaves in ChFT were due to these sources increasing nutrient concentrations in plant organs (Souri, 2016).

Potassium was concentrated in greater amounts in the new leaves in the two treatments. This is because K is an element in constant movement within the plant and is translocated from old leaves to young ones, since the latter are metabolically more active (Singh, 2021). Likewise, Cochrane and Cochrane (2009) indicate that when young leaves are potassium-deficient, the element is translocated from old leaves.

Comparing treatments, K concentration was higher in ChFT (Table 3) because chelates neutralize the element's ionic charge, facilitating its transfer to the different organs of the plant (Sardans and Peñuelas, 2021). This statement is reinforced by the analysis of the interaction between treatment and leaf maturity: ChFT had a higher concentration of this element in newer leaves, whereas CFT plants had a lower concentration of this element in old and intermediate leaves.

At the three leaf-maturity levels, ChFT had higher potassium concentrations; for example, in old ChFT leaves, the concentration was 11 762 mg L^{-1}, whereas in CFT, it was 10 009. It is possible that, in the latter case, there was greater translocation toward the young leaves, since it also had the lowest concentration of this element.

Magnesium concentration was higher in older ChFT leaves, whereas newer leaves in both treatments had a lower concentration of this element (Table 3). This result may be partly explained by the fact that this element is part of the structure of chlorophyll and is bound to the chloroplast, so translocation from old leaves is more difficult than that of potassium; in addition, old leaves have had more time to accumulate this element in their cells.

An imbalance in the Mg-K interaction may also occur due to excess K, hindering its transport to young leaves (Xie *et al*., 2021).

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Fruit quality

Number and weight of fruits

On most harvest dates, fruits weighed more under the chelated fertilizer treatment. In the extra-large and large categories, the chelated fertilizer treatment produced more fruits, with a percentage rate of variation (PRV) of 17.1 and 4.6%, respectively (Table 4). In contrast, CFT produced more medium and small fruits.

Table 4. Distribution of cucumber fruits by market quality classification according to their weight.

Category	Weight (g)	Chelated		Conventional		p	PRV
		(%)	Number	(%)	Number		
Extra-large	>400	6.62	44	5.9	38	0.650	17.1
Large	300 to 400	88.46	588	88.29	562	0.93	4.6
Medium	200 to 300	4.91	33	5.8	37	0.54	-11.6
Small	100 to 200	0	0	0	0	-	0
Total		100	665	100	637	-	4.4

p= statistical significance using Fisher's exact test; PRV= percentage rate of change.

Fruit length

In ChFT, more fruits were developed in the long and super-select categories, with PRVs of 155.5 and 36.1%; respectively, compared with those obtained in CFT (Table 5). In contrast, the latter treatment produced the smallest fruits, since the select and small categories had PRVs of -18.1 and 47.6%, respectively, compared with the chelated treatment.

Table 5. Distribution of cucumber fruits by their market quality classification according to their length.

Category	Length (cm)	Chelated		Conventional		p	PRV
		(%)	Number	(%)	Number		
Large	>25.5	6.79	45	2.78	18	0.001	155.5
Super select	24 to 25.5	45.68	304	35.05	223	<0.0001	36.1
Select	22 to 24	45.28	301	57.69	367	<0.0001	-18.1
Small	20 to 22	2.25	15	4.49	29	0.031	-47.6
Total		100	665	100	637	-	4.4

p= statistical significance using Fisher's exact test; PRV= percentage rate of variation.

Higher fruit weight led to greater yield in the chelated fertilizer treatment. In this regard, Liu *et al*. (2021) obtained better yields in their crops with chelated fertilizer application, which also increased fruit quality and nutrient concentration. One reason is that amino acid chelates improve nutrient absorption, thereby increasing plant growth and yield (Souri, 2016). For example, potassium contributed to plant development by participating in osmotic adjustment, stomatal opening and closing, and enzymatic activation (Ahmad *et al*., 2018).

The greater number of fruits, along with the greater fruit weight and length in the chelated treatment, is reflected in higher crop yield, since ChFT plants had an average yield of 5.9 kg, whereas CFT had a yield of 5.4 kg (Table 6).



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Table 6. Comparison of fruit yield by treatment.

Treatment	kg plant^{-1}	Standard deviation
CFT	5.4	0.525
ChFT	5.9	0.498

This aligns with the results of Navarro-León *et al*. (2022), who reported a higher yield and better quality of pepper fruits in treatments using chelates. Likewise, our results align with Kim *et al*. (2013) and Liu *et al*. (2021), who obtained heavier cucumber fruits in the chelate treatment, thereby increasing crop productivity and improving quality.

Firmness and soluble solids concentration in cucumber fruit

The fruits developed in plants treated with chelates had an average firmness of 3.93 kg cm^{-1}, which was higher (p= 0.001) than that of the fruits developed with CFT, which had an average firmness of 3.78 kg cm^{-1} (Table 7). The increase in firmness in the cucumber fruits treated with chelates could be caused by the high concentration of calcium that this treatment presented in the fruits, coinciding with the results obtained by Navarro-León *et al*. (2022), who found a higher concentration of this element in pepper fruits, resulting in an increase in fruit firmness and size.

Table 7. Firmness and soluble solids concentration in cucumber fruits by treatment ± standard deviation.

Treatment	Firmness (kg cm^{-2})	Soluble solids concentration (Brix)
CFT	3.78 ±0.074	1.22 ±0.134
ChFT	3.93 ±0.066	1.34 ±0.063
p-value	0.004	0.001

The concentration of soluble solids was also higher (p= 0.003) in fruits with chelated fertilization, at 1.34 Brix, while fruits from plants developed in CFT had a concentration of 1.22 Brix. The increase in the concentration of soluble solids in cucumber fruits treated with chelates may be related to the high concentration of potassium that these fruits had, compared to those subjected to conventional fertilization, coinciding with the results presented by Alejo-Santiago *et al*. (2021), who found a positive correlation between the concentration of potassium in the nutrient solution applied and the content of total soluble solids (Brix) in cucumber fruits.

Conclusions

Applying chelated Ca, K and Mg fertilizers lead to higher concentrations of these elements in stems, leaves and fruits, mainly Ca and K in leaves, because their mobility in the plant is facilitated. This results in better plant development than with conventional fertilization, under shade-net conditions, reflected in greater weight, length, firmness and higher Brix concentration in fruit, as well as higher crop yield.

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