Influence of the $K^+/Ca^{2+}+Mg^{2+}$ ratio in the yield of zucchini (*Cucurbita pepo* L.)

Influencia de la relación $K^+/Ca^{2+}+Mg^{2+}$ en el rendimiento de calabacita (*Cucurbita pepo* L.)

Influência da relação $K^+/Ca^{2+}+Mg^{2+}$ na produtividade de abobrinha (*Cucurbita pepo* L.)

Rolando Rueda-Luna[1]
Jenaro Reyes-Matamoros[1*]
Miriam Romero-Hernández[1]
Raymundo Hernández-Loma[2]
Abel Cruz-Montalvo[1]

[1]Centro de Investigación en Ciencias Agrícolas. Benemérita Universidad Autónoma de Puebla (BUAP). Av. 14 Sur 6301, CU, Col. San Manuel, C.P. 72570, Puebla, Pue., México
[2]Facultad de Ingeniería Agroindustrial, Complejo Regional Centro, Sede Tecamachalco, Benemérita Universidad Autónoma de Puebla (BUAP). Km 7.5 carretera Cañada Morelos, El Salado Tecamachalco, Pue., México

Rev. Fac. Agron. (LUZ). 2025, 42(1): e244215
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v42.n1.XV

Crop production

Associate editor: Dr. Jorge Vilchez-Perozo
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Received: 19-11-2024
Accepted: 29-01-2025
Published: 24-02-2025

Keywords:
Cationic ratio
Mineral balance
Nutrient uptake
Greenhouse production

Abstract

Zucchini (*Cucurbita pepo* L.) is a widely cultivated vegetable that plays a significant role in global food production. Its yield and nutritional composition are influenced by various agronomic factors, including the availability and balance of essential nutrients. Among these, the cationic ratio of potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) in the nutrient solution is critical for plant growth and productivity due to their interactive effects on absorption and transport. The objective of this study was to evaluate the impact of different $K^+/Ca^{2+}+Mg^{2+}$ ratios on the yield and mineral composition of zucchini leaves. The experiment was conducted under greenhouse conditions using a factorial design with two commercial varieties (Zuchinni Gray and Ambrosia) and five nutrient solutions with different cation ratios ($K^+/Ca^{2+}+Mg^{2+}$; 0.2, 0.6, 1.0, 1.4, and 1.8). Plants were grown in polyethylene containers filled with red tezontle substrate. The results showed that Ambrosia exhibited a higher total yield compared to Zuchinni Gray. The $K^+/Ca^{2+}+Mg^{2+}$ ratios of 1.4 and 1.8 significantly increased total production, while the ratio of 1.4 enhanced calcium absorption. However, no significant differences were observed in potassium and magnesium content in the leaves. These findings highlight the importance of optimizing the cationic balance in the nutrient solution to improve zucchini productivity and mineral composition.

*Corresponding author:jenaro.reyes@correo.buap.mx

Resumen

La calabacita (*Cucurbita pepo* L.) es una hortaliza ampliamente cultivada que desempeña un papel significativo en la producción mundial de alimentos. Su rendimiento y composición nutricional están influenciados por diversos factores agronómicos, incluida la disponibilidad y el equilibrio de nutrientes esenciales. Entre estos, la relación catiónica de potasio (K^+), calcio (Ca^{2+}) y magnesio (Mg^{2+}) en la solución nutritiva es crítica para el crecimiento y la productividad de la planta debido a sus efectos interactivos en la absorción y el transporte. El objetivo de este estudio fue evaluar el impacto de diferentes relaciones $K^+/Ca^{2+}+Mg^{2+}$ sobre el rendimiento y la composición mineral de las hojas de calabacita. El experimento se llevó a cabo en condiciones de invernadero utilizando un diseño factorial con dos variedades comerciales (Zuchinni Gray y Ambrosia) y cinco soluciones nutritivas con diferentes relaciones catiónicas ($K^+/Ca^{2+}+Mg^{2+}$; 0.2, 0.6, 1.0, 1.4 y 1.8). Las plantas se cultivaron en contenedores de polietileno llenos con sustrato de tezontle rojo. Los resultados mostraron que la variedad Ambrosia presentó un mayor rendimiento total en comparación con Zuchinni Gray. Las relaciones $K^+/Ca^{2+}+Mg^{2+}$ de 1.4 y 1.8 incrementaron significativamente la producción total, mientras que la relación de 1.4 favoreció la absorción de calcio. Sin embargo, no se observaron diferencias significativas en el contenido de potasio y magnesio en las hojas. Estos hallazgos resaltan la importancia de optimizar el equilibrio catiónico en la solución nutritiva para mejorar la productividad y la composición mineral de la calabacita.

Palabras clave: relación catiónica, balance mineral, absorción de nutrientes, producción en invernadero.

Resumo

A abobrinha (*Cucurbita pepo* L.) é uma hortaliça amplamente cultivada que desempenha um papel significativo na produção mundial de alimentos. Seu rendimento e composição nutricional são influenciados por diversos fatores agronômicos, incluindo a disponibilidade e o equilíbrio de nutrientes essenciais. Entre esses fatores, a relação catiônica de potássio (K^+), cálcio (Ca^{2+}) e magnésio (Mg^{2+}) na solução nutritiva é crucial para o crescimento e a produtividade das plantas devido aos seus efeitos interativos na absorção e no transporte de nutrientes. O objetivo deste estudo foi avaliar o impacto de diferentes relações $K^+/Ca^{2+}+Mg^{2+}$ no rendimento e na composição mineral das folhas de abobrinha. O experimento foi conduzido em condições de estufa, utilizando um delineamento fatorial com duas variedades comerciais (Zuchinni Gray e Ambrosia) e cinco soluções nutritivas com diferentes relações catiônicas ($K^+/Ca^{2+}+Mg^{2+}$; 0,2, 0,6, 1,0, 1,4 e 1,8). As plantas foram cultivadas em recipientes de polietileno preenchidos com substrato de tezontle vermelho. Os resultados mostraram que a variedade Ambrosia apresentou maior rendimento total em comparação com a Zuchinni Gray. As relações $K^+/Ca^{2+}+Mg^{2+}$ de 1,4 e 1,8 aumentaram significativamente a produção total, enquanto a relação de 1,4 favoreceu a absorção de cálcio. No entanto, não foram observadas diferenças significativas nos teores de potássio e magnésio nas folhas. Esses achados destacam a importância da otimização do equilíbrio catiônico na solução nutritiva para melhorar a produtividade e a composição mineral da abobrinha.

Palavras-chave: relação catiônica, equilíbrio mineral, absorção de nutrientes, produção em estufa.

Introduction

The immature fruits of the zucchini (*Cucurbita pepo* L.) are primarily consumed, as a vegetable, in both domestic and export markets. Over the past decade, the cultivation of this vegetable has experienced a period of sustained growth in the state of Puebla, ranking first among vegetables utilized for their fruit. The cultivated area has reached 4,080.36 hectares, with an average yield of 17.44 $t.ha^{-1}$ (SIAP, 2023). However, this yield is below the national average of 21.23 $t.ha^{-1}$ (SIAP, 2023). This issue may be attributed to the dearth of varieties that are tolerant to the particular conditions of the region, the prevalence of pests and diseases, inadequate plant nutrition, and other technological requirements (SDR, 2007). Conversely, excessive application of fertilizers to agricultural soils can result in long-term salinization and the loss of beneficial soil microorganisms, as well as environmental contamination (Santos-Coello & Ríos-Mesa, 2016). It is therefore necessary to maximize the utilization of nutrient by crops through the administration of appropriate doses of fertilizer. The availability of cations such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) in relation to their absorption, transport, and utilization by plants depends on maintaining a proper balance between them, which must be achieved for optimal absorption (Cadahía-López, 2005). As indicated by Havlin *et al*. (2017) the efficiency of plant absorption of K^+ is influenced by the presence of Ca^{2+} and Mg^{2+}, particularly. Therefore, the relationship between these cations serves as an indicator of the labile K in the soil, representing the quantity of potassium that is immediately accessible to crop roots. Furthermore, the literature mentions that nutrient absorption in *C. pepo* during the growing season exhibits a positive linear trend (Rodas-Gaitán *et al*., 2012).

In recent years, generated technology has been developed with the objective of enhancing the efficiency and sustainability of the agricultural production systems, This has been done, with the intention of reducing costs, increasing profitability, ensuring the provision of safe food, and mitigating the negative environmental impacts resulting from the excessive use of agrochemicals (Aguilar-Carpio *et al*., 2022). In this regard, a valuable approach is to ascertain the nutrient demand of cultivated species, considering both nutrient absorption efficiency and the utilization of the fertilizer source, and subsequently devise an effective fertilization plan (Estrada-Herrera *et al*., 2017). It is beyond question that the study of crop nutrition plays a fundamental role (Alcántar-González & Trejo–Téllez, 2010). Accordingly, the objective of this study was to evaluate the impact of the $K^+/Ca^{2+}+Mg^{2+}$ ratio on the yield and nutritional composition of zucchini leaves.

Materials and methods

The experiment was conducted at the facilities of the Agricultural Sciences Research Center at the Benemérita Universidad Autónoma de Puebla, Puebla, Mexico. The center is located at 19° 14’ north latitude and 98° 18’ west longitude, at an altitude of 2150 meters above sea level (INEGI, 2014). The crop was cultivated in a tunnel-type greenhouse with milky white plastic cover and 25 % shade netting. On January 18, 2023, the seedlings were transplanted at the two true leaf stage into polyethylene containers measuring 30 x 40 cm

and filled with red tezontle, a substrate comprising particles less than 16 mm in size. The planting layout was arranged in double rows with a distance of 1.5 meters between rows and a distance of 0.25

meters between plants, resulting in a population density of 2.6 plants per square meter. Irrigation was conducted manually, with volume applied depended on the phenological stage, while maintaining a drainage volume of 30 % starting from the time of transplantation onwards. The irrigation sheet was applied as follows: 300 mL per plant during the vegetative stage, 600 mL during flowering, 1000 mL during fruiting, and 1200 mL during the harvest period.

Two different commercial varieties of zucchini were utilized in this study. The varieties of zucchini utilized in the study were Zuchinni Gray and Ambrosia. Five nutrient solutions with varying cation ratios ($K^+/Ca^{2+}+Mg^{2+}$; 0.2, 0.6, 1.0, 1.4, and 1.8) were employed. The experiment was designed in a 2 x 5 factorial arrangement, with two varieties of zucchini and five proposed nutrient solutions, replicated three times, for a total of 30 experimental units (R.U.). The final nutrient solutions for potassium were as follows: The concentrations of potassium, calcium, and magnesium were 6.28, 6.01, 7.5, 7.25, and 9.0, 6.7, 3.21, 2.35, and 1.01, 1.35, respectively. The respective concentrations of potassium, calcium, and magnesium in $meq.L^{-1}$ were 5.7, 1.55, 1.22, 1.41, and 1.1 for each ratio of $K^+/Ca^{2+}+Mg^{2+}$. The remaining elements were maintained at a constant level in all cases, with the pH of the various nutrient solutions adjusted to a value of 6.5.

The harvest index and frequency were defined based on commercial maturity criteria commonly used for zucchini harvesting (Maroto-Borrego, 2002). A total of 10 harvest dates were recorded throughout the production cycle. The total production, accumulated over 10 harvest dates, dry and fresh leaf weights, and the content of K, Ca, and Mg were evaluated in mature leaves collected at the fruiting stage. The corresponding readings were obtained using an atomic absorption spectrophotometer (Varian brand, model SpectrAA 55B®). The results were subjected to analysis of variance (ANOVA), and mean comparisons were made using the Tukey test, which was performed using the statistical software package Statgraphics version 4.1 Centurion.

Results and discussion

The results show a clear varietal effect, with Ambrosia displaying superior total production, fruit count, and fruit length in comparison to Zuchinni Gray, exhibiting statistically significant differences ($p \leq 0.05$) (table 1).

This finding aligns with Purquerio *et al*. (2019), who observed significant differences in growth and yield among zucchini cultivars, with varying nutrient management resulting in substantial differences in biomass accumulation and fruit yield. However, the highest mean fruit weight was observed for Zuchinni Gray with statistically significant differences ($p \leq 0.05$), and were while no differences were noted in fruit diameter. Regarding the $K^+/Ca^{2+}+Mg^{2+}$ ratio, plants that received the nutrient solution with a ratio of 1.4 and 1.8 exhibited enhanced total production and a greater number of fruits with statistically significant differences ($p \leq 0.01$). These findings suggest a correlation between elevated $K^+/Ca^{2+}+Mg^{2+}$ ratios and enhanced productivity. Moreover, the interaction results demonstrated that the Ambrosia variety exhibited a greater productivity advantage, both in terms of total production and fruit count, with a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.8. Conversely, the Zuchinni Gray variety demonstrated superior performance with a ratio of 1.4 in terms of total production. However, regarding fruit count, the 1.8 ratio exhibited the highest value (Table 2). Seth *et al*. (2018) emphasized that the $K^+/Ca^{2+}+Mg^{2+}$ ratio plays a crucial role in the efficiency of potassium uptake, influencing overall plant growth and yield, which supports our findings of a stronger productivity response in plants receiving nutrient solutions with higher $K^+/Ca^{2+}+Mg^{2+}$ ratios. Similarly, Neocleous & Savvas (2018) found that increasing calcium concentrations can affect the uptake of other macronutrients and overall plant growth, further highlighting the importance of optimizing nutrient ratios in promoting healthy, productive crops.

In terms of fresh and dry leaf weight (Table 3), the results indicate the absence of statistically significant differences between the varieties. Regarding the $K^+/Ca^{2+}+Mg^{2+}$ ratio, higher dry weight was recorded with a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.0 with statistically significant differences ($p \leq 0.01$). However, the different $K^+/Ca^{2+}+Mg^{2+}$ ratios in the nutrient solution did not affect the fresh leaf weight of the plants, as no clear differences were observed between the treatments.

Table 4 presents the results of the foliar analysis conducted during the fruiting stage. At the varietal level, no differences were observed in the mineral elements of potassium and magnesium. However, a higher concentration of calcium (4377.0 ppm) was observed in Ambrosia compared to Zuchinni Gray (4156.33 ppm), with statistically significant differences ($p \leq 0.05$). Regarding the different $K^+/Ca^{2+}+Mg^{2+}$ ratios, no differences were observed with respect to potassium and magnesium. However, the plants that received the nutrient solution with a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.0 and 1.4 exhibited the highest calcium contents (4550.0 ppm in both cases), with significant differences ($p \leq 0.01$). No statistically significant differences were observed in the variety x $K^+/Ca^{2+}+Mg^{2+}$ ratio interaction.

Table 1. Productive parameters of Zucchini.

		Total production (g/R.U.)	Number of fruits (R.U.)	Average weight (g/R.U.)	Fruit diameter (cm)	Fruit length (cm)
Variety	Ambrosia	3237.79 ± 400.99 a	20.53 ± 2.16 A	155.3 ± 5.53 b	4.61 ± 0.19 ns	14.77 ± 0.51 a
	Zuchinni Gray	2541.72 ± 352.99 b	14.67 ± 2.36 B	169.39 ± 13.09 a	4.73 ± 0.36 ns	13.71 ± 0.42 b
$K^+/Ca^{+2}+Mg^{+2}$ Ratio	0.2	1269.33 ± 332.28 B	10.67± 2.63 C	116.0 ± 2.68 C	3.92 ± 0.49 B	12.83 ± 0.54 B
	0.6	2797.2 ± 282.17 AB	12.67 ± 1.91 BC	212.78 ± 20.3 A	5.08 ± 0.63 AB	14.62 ± 0.87 AB
	1.0	2652.07 ± 506.71 AB	16.67 ± 2.99 ABC	158.15 ± 6.93 B	5.53 ± 0.29 A	15.88 ± 0.41 A
	1.4	3467.31 ± 443.74 A	22.67 ± 3.68 AB	156.85 ± 5.43 B	4.18 ± 0.21 AB	13.48 ± 0.46 AB
	1.8	4262.87± 702.29 A	25.33 ± 3.91 A	167.96 ± 3.41 B	4.65 ± 0.18 AB	14.40 ± 0.9 AB
Interaction	Variety x Ratio	**	**	**	**	*

Different letters (uppercase/lowercase) in the same column indicate statistically significant differences at 99 % and 95 % respectively according to the Tukey test. Not significant (ns), significance level at 0.05 (*), 0.01 (**). R.U.: Repetition unit (3 plants).

Table 2. Interaction of zucchini production parameters.

Variety	$K^+/Ca^{+2}+Mg^{+2}$ ratio	Total production (g/R.U.)	Total number of fruits	Average weight (g/R.U.)	Fruit diameter (cm)
Ambrosia	0.2	1952.0 c	16.0 b	122.0 b	5.0 a
	0.6	2471.73 b	14.67 b	170.34 a	4.07 a
	1.0	3396.13 b	21.33 b	157.3 b	5.23 a
	1.4	2781.33 b	17.33 b	160.63 b	3.8 a
	1.8	5587.73 a	33.33 a	166.25 b	4.96 a
Zuchinni Gray	0.2	586.66 c	5.33 a	110.00 b	2.83 b
	0.6	3122.67 b	10.67 a	255.21 a	6.08 a
	1.0	1908.0 b	12.0 a	159.0 a	5.83 a
	1.4	4153.28 a	28.0 a	153.07 a	2.88 b
	1.8	2938.0 b	17.33 b	169.66 a	4.33 a
LSD ($p\leq0.05$)		1433.56	9.17	23.64	1.74

Means with the same letter are equal at significance level $p\leq0.05$. R.U.: Repetition unit (3 plants)

Table 3. Weight of developed zucchini leaves at fruiting stage.

		Fresh weight (g/R.U.)	Dry weight (g/R.U.)
Variety	Ambrosia	27.85 ± 1.1 ns	4.18 ± 0.24 ns
	Zuchinni Gray	26.18 ± 1.05 ns	3.69 ± 0.28 ns
$K^+/Ca^{+2}+Mg^{+2}$ Ratio	0.2	26.06 ± 1.59 ns	3.16 ± 0.3 B
	0.6	26.18 ± 1.91 ns	3.33 ± 0.42 B
	1.0	30.5 ± 1.33 ns	5.11 ± 0.27 A
	1.4	25.67 ± 1.17 ns	3.83 ± 0.28 AB
	1.8	26.67 ± 2.12 ns	4.25 ± 0.3 AB
Interaction	Variety x Ratio	ns	ns

Different letters in the same column indicate statistically significant differences at 99 % according to the Tukey test. Not significant (ns). R.U.: Repetition unit (3 plants).

Table 4. $K^+/Ca^{+2}+Mg^{+2}$ ratio in zucchini leaves.

		K (ppm)	Ca (ppm)	Mg (ppm)
Variety	Ambrosia	4095.0 ± 82.39 ns	4377.0 ± 107.19 A	2120.0 ± 89.17 ns
	Zuchinni Gray	4185.0 ± 116.77 ns	4156.33 ± 84.75 B	2125.0 ± 112.14 ns
$K^+/Ca^{+2}+Mg^{+2}$ Ratio	0.2	4062.5 ± 170.65 ns	4063.33 ± 65.8 B	2150.0 ± 71.22 ns
	0.6	4100.0 ± 146.24 ns	4062.5 ± 145.04 B	2112.5 ± 223.18 ns
	1.0	4112.5 ± 157.39 ns	4550.0 ± 110.37 A	2212.5 ± 129.66 ns
	1.4	4225.0 ± 161.09 ns	4550.00 ± 81.75 A	2050.0 ± 185.12 ns
	1.8	4200.0 ± 199.8 ns	4107.5 ± 211.82 B	2087.5 ± 186.13 ns
Interaction	Variety x Ratio	ns	ns	ns

Different letters in the same column indicate statistically significant differences at 99 % according to the Tukey test. Not significant (ns).

The analysis of the results indicates that the Ambrosia variety exhibited superior productivity compared to Zuchinni Gray, which could be attributed to a varietal response. In order to ascertain the average fruit weight, and in considering of fruit maturity, the reference values proposed by Maroto-Borrego (2002) were employed. These values indicate that commercially viable fruits should exhibit a length of 15-18 cm and a weight of 200-250 g at the time of harvesting.

The $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.4 and 1.8 was observed to increase total production in both cultivars, indicating a trend towards higher productivity with higher $K^+/Ca^{2+}+Mg^{2+}$ ratios. These results align with the findings of Seth *et al*. (2018), who point out that the availability and absorption of K^+ are influenced by the proportion of the competing cations Ca^{2+} and Mg^{2+}, and that an optimal K^+ ratio promotes greater productivity in different cropping systems. Additionally, Purquerio *et al*. (2019) observed a similar trend in zucchini where higher nutrient uptake, particularly of potassium, led to improved yields and plant growth. However, the interaction results indicate that the Ambrosia variety exhibits greater productivity with a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.8 (yielding 1.86 kg per plant), while the Zuchinni Gray variety demonstrates a superior response to a ratio of 1.4 (yielding 0.93 kg per plant). These values are below those reported by Moreno-Reséndez *et al*. (2019) for the Mona Lisa F1 hybrid, which yielded 3.987 kg per plant. These discrepancies could be attributed to the differing nutrient requirements of the cultivars.

The highest dry leaf weight was observed when the $K^+/Ca^{2+}+Mg^{2+}$ ratio was 1.0. However, the different $K^+/Ca^{2+}+Mg^{2+}$ ratios in the nutrient solution did not affect the dry leaf weight of the plant. Nevertheless, they could influence greater calcium assimilation and a potential increase in average fruit weight. The results suggest that the optimal $K^+/Ca^{2+}+Mg^{2+}$ ratio in plant nutrition may be established a balance point between production and dry plant weight, situated between 1.0 and 1.8 (in meq.L^{-1}). These values may be considered as reference indices for zucchini cultivation. Similar results were reported by Diovisalvi *et al*. (2021) in a study of different soybean crop nutrition. In a related study, Aguilar-Carpio *et al*. (2022) observed that the integration of chemical fertilization with biostimulants, such as seaweed extracts, resulted in enhanced growth, yield, and profitability in zucchini. These findings highlight the potential of optimized nutrient management strategies to enhance crop productivity. In line with this, Melito *et al*. (2023) found that applying appropriate levels of organic-mineral fertilizers increased the growth and yield of zucchini, supporting the notion that nutrient optimization plays a significant role in enhancing zucchini productivity.

The results of the leaf analysis reflect a higher concentration of calcium (4377.0 ppm) in Ambrosia compared to Zuchinni Gray (4156.33 ppm). Similarly, the highest calcium values were recorded in plants that received the nutrient solution with a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.0 and 1.4, with values of 4550.0 ppm in both cases. The statistical analysis revealed no significant differences in the mineral elements potassium and magnesium among the cultivars or across the different $K^+/Ca^{2+}+Mg^{2+}$ ratios.

The overall, the assimilation of cations K^+, Ca^{2+} and Mg^{2+} was found to be similar between the evaluated cultivars, irrespective of the harvest date. The absorption of potassium (4225.0 ppm) was higher following fruit formation with a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.4, as potassium is an element that typically influences fruit coloration, increasing pigmentation by raising carotenoid content while reducing chlorophyll content (CPHA, 2004). Furthermore, the absorption of calcium reached concentrations of 4550.0 ppm, while magnesium reached 2050.0 ppm. These results are in accordance with the findings of Rodas-Gaitán *et al*. (2012), who observed that in zucchini, calcium was the primary absorbed element at 7.47, followed by magnesium at 2.07 and potassium at 1.37 g.$plant^{-1}$. However, the present study revealed higher potassium concentration was observed. With regard to calcium, its assimilation also increased during the fruiting stage with the highest contents observed in the leaves of plants that received a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.0 and 1.4. In contrast, plants that received a $K^+/Ca^{2+}+Mg^{2+}$ ratio of 0.2 and 0.6 exhibited the lowest calcium contents across all evaluated physiological stages, potentially due to the antagonism relationship between the Ca^{2+} ion and K^+ (Villalobos *et al*., 2009). This further supports the idea that nutrient balance, especially between calcium and potassium, plays a key role in determining plant health and fruit yield (Neocleous & Savvas, 2018). Seth *et al*. (2018) similarly found that an optimal balance between K^+, Ca^{2+}, and Mg^{2+} is essential for maximizing nutrient uptake and minimizing the antagonistic effects between these cations.

Conclusions

It can be concluded that there is a varietal effect, with the Ambrosia variety demonstrating a higher total production compared to Zuchinni Gray. The $K^+/Ca^{2+}+Mg^{2+}$ ratio significantly influenced the yield and nutritional composition of zucchini, with Ambrosia showing superior productivity compared to Zuchinni Gray. The $K^+/Ca^{2+}+Mg^{2+}$ ratio with a value of 1.4 (Ambrosia) and 1.8 (Zuchinni Gray) was observed to increase total production, which could be considered as a reference for zucchini cultivation. The optimal ratio of 1.4 to 1.8 promoted increased total production, fruit count, and enhanced calcium absorption. Moreover, the $K^+/Ca^{2+}+Mg^{2+}$ ratio of 1.4 led to an increase in leaf calcium content, while the potassium and magnesium contents remained constant.

Literature cited

Aguilar-Carpio, C., Cervantes-Adame, Y.F., Sorza-Aguilar, P.J., & Escalante-Estrada, J.A.S. (2022). Growth, yield, and profitability of zucchini (*Cucurbita pepo* L.) fertilized with chemical and biological sources. *Revista Terra Latinoamericana*, *40*, e1059. https://doi.org/10.28940/terra.v40i0.1059

Alcántar-González, G., y Trejo-Téllez, L.I. (2010). Nutrición de cultivos. Colegio de Posgraduados, Mundi–Prensa, México, 454 pp. ISBN 978-968-7462-48-6

Cadahía-López, C. (2005). Fertirrigación. Cultivos agrícolas, frutales y ornamentales. 3a Edición, Mundi-Prensa, Madrid, España, 631 pp. ISBN 84-8476-247-5

CPHA. (2004). Manual of fertilizers for high yield crops. California Plant Health Association, Editorial Limusa. 366 pp. ISBN: 978-9681847661

Diovisalvi, N.V., Reussi-Calvo, N.I., Boxler, M., y García, F. (2021). Relevamiento de calcio, magnesio, potasio y micronutrientes en zonas con diferente productividad de soja. *Ciencia del Suelo*, *39*(1), 63-79. https://www.scielo.org.ar/pdf/cds/v39n1/1850-2067-cds-39-01-63.pdf

Estrada-Herrera, R., Hidalgo-Moreno. C., Guzmán-Plazola, R., Almaraz-Suárez, J.J., Navarro-Garza, H., & Etchevers-Barra, J.D. (2017). Soil quality indicators to evaluate soil fertility. *Agrociencia*, *51*, 813-831. https://www.scielo.org.mx/pdf/agro/v51n8/1405-3195-agro-51-08-813-en.pdf

Havlin, J.L., Tisdale, S.L., Nelson, W.L., & Beaton, J.D. (2017). Soil fertility and fertilizers: An Introduction to Nutrient Management. 8th edition, India Education Services Pvt. Ltd: Pearson. ISBN 978-93-325-7034-4

INEGI. (2014). Anuario estadístico y geográfico de Puebla. Instituto Nacional de Estadística y Geografía, México. https://www.inegi.org.mx

Maroto-Borrego, J.V. (2002). Horticultura herbácea especial. 5ª Edición, Ediciones Mundi-Prensa, España, 704 pp. ISBN 978-8484760429

Melito, S., Ronga, D., Marceddu, D., Kallikazarou, N.I., Antoniou, MG., & Giannini, V. (2023). Organo-mineral fertilizer containing struvite from liquid digestate for *Cucurbita pepo* L. seedling production. *Journal of Soil Science and Plant Nutrition*, *23*, 6707-6720. https://doi.org/10.1007/s42729-023-01524-9

Moreno-Reséndez, A., Reyes-Carrillo, J.L., Preciado-Rangel, P., Ramírez-Aragón, M.G., y Moncayo-Luján, M.R. (2019). Desarrollo de la calabacita (*Cucurbita pepo* L.) con diferentes fuentes de fertilización bajo condiciones de invernadero. *Ecosistemas y Recursos Agropecuarios*, *6*(16), 145-151. https://doi.org/10.19136/era.a6n16.1803

Neocleous, D., & Savvas, D. (2018). Modelling Ca^{2+} accumulation in soilless zucchini crops: Physiological and agronomical responses. *Agricultural Water Management*, *203*, 197-206. https://doi.org/10.1016/j.agwat.2018.03.017

Purquerio, L.F.V., Mattar, G.S., Duart, A.M., de Moraes, C.C., Araújo, H.S., & Santos, F.F.D. (2019). Growth, yield, nutrient accumulation and export and thermal sum of Italian zucchini. *Horticultura Brasileira*, 37, 221-227. http://dx.doi.org/10.1590/S0102-053620190214

Rodas-Gaitán, H.A., Rodríguez-Fuentes, H., Ojeda-Zacarías, Ma. del C., Vidales-Contreras, J.A., y Luna-Maldonado, A.I. (2012). Curvas de absorción de macronutrientes en calabacita italiana (*Cucurbita pepo* L.). *Revista Fitotecnia Mexicana*, *35*(5), 57–60. https://revistafitotecniamexicana.org/documentos/35-3_Especial_5/10r.pdf

Santos-Coello, B., y Ríos-Mesa, D. (2016). Cálculo de soluciones nutritivas en suelo y sin suelo. Servicio de Agricultura y Desarrollo Rural, Cabildo Insular de Tenerife, España, 113 pp. ISBN 978-84-15012-87-0

SDR. (2007). Cadenas productivas agropecuarias y acuícolas del Estado de Puebla. Secretaría de Desarrolla Rural, Gobierno del Estado de Puebla, México, pp. 89-90.

Seth, A., Gothelf, R., & Shenker, M. (2018). The K to (Ca + Mg) ratio effect on potassium availability for plants - splitting soil- from plant-related interactions. In: 20th EGU General Assembly, Geophysical Research Abstracts, Vienna, Austria, 20, p. 9425.

SIAP. (2023). Anuario estadístico de la producción agrícola. Servicio de Información Agroalimentaria y Pesquera, México. https://nube.siap.gob.mx/cierreagricola/

Statgraphics Centurion XVI version 16.1.18 for Windows. ©StatPoint Technologies, Inc., 1982-2012, USA.

Villalobos, F.C., Mateos, L., Orgaz, F., y Fereres, E. (2009). Fitotecnia: Bases y tecnologías de producción agrícola. 2a edición, Editorial Mundi-Prensa. Madrid, España, 496 pp. ISBN 978-84-8476-037-5