Sustainable Agriculture Research; Vol. 7, No. 2; 2018
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

# Influence of the $K^+$ and $Ca^{2+}$ on the Presence of Sugars in the Phloem, and Growth Parameters in *Capsicum*

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Received: September 20, 2017 Accepted: October 4, 2017 Online Published: January 27, 2018

doi:10.5539/sar.v7n2p1 URL: https://doi.org/10.5539/sar.v7n2p1

**Abstract**

The effect of various $K^+$ and $Ca^{2+}$ nutrient solutions were evaluated to measure the growth rate, amount of reducing sugars and the production of Capsicum annuum Plants were grown directly in soil under shade house conditions in two separate experiments across two consecutive years. Nine nutrient solutions containing three levels of K+ (27, 35 and 43%) combined with three levels of $Ca^{2+}$ (37, 45 and 53%) were used, along with the Steiner solution treatment as a control. Irrigation was calculated every week according to Kc, volumetric humidity and ETo, the experimental design was a block (furrows) with a 3(x)3 factorial arrangement. There was no interaction between growth rate, sugars and yield. Plants treated with the combination 27% of potassium with 53% of calcium presented a yield of 500 g/fruit greater than the control treatment (Steiner), and produced on average 2 more fruits per plant with a weight of 160 g/fruit (<0.05) higher than Steiner, the low potassium concentration (27%) induced a lower concentration of sugars with a value >3 mg/ml during the first crop cycle, it were analyzed during the flowering stage, and in the second agricultural cycle, during the fruiting stage it was < 4 mg/ml.

**Keywords**: glucose, fructose, chili, yield, plant nutrition

## 1. Introduction

México is the second largest world producer of Capsicum annuum, with 2,131,740 tonnes annually. In Mexico, bell pepper is produced mainly in the northwestern and part of the central regions, with a national production of 206,227 tons, of which Sinaloa contributes 175,694 tons, or 86% of the national total. Plant nutrition is determinant to increase yields, however, nutrient excess causes contamination of soils and waters (Oliveira *et al*., 2013) and the actual tendency is to replace traditional methods of nutrition for more sustainable management techniques on profitable crops, especially horticultural crops grown in protected systems (Khan and Shah, 2011; Nunes-Júnior *et al*., 2017).

Pepper growth and development is determined in phenological stages (USDA, 2003, Moreno *et al*., 2011). The addition of fertilizers is required, stating from its establishment (Kant *et al*., 2005). This is commonly achieved by fertigation to obtain a well developed and high quality plant (Royo *et al*., 1998), with increased yields (Parra-Terraza *et al*., 2008). Fertilizers influences quality parameters such as glucose and fructose (Lester *et al*., 2010).

Potassium $K^+$ is absorbed mainly in roots (Maathuis and Sanders, 1994). The absorption is more common in ionic form of inorganic sources and mainly monovalent elements (Frageria, 2013; Mengutay *et al*., 2013), $K^+$ Participates in physiological functions, such as pH regulation and osmotic regulation of plants. It also participates in the fixation of atmospheric $N_2$ in legumes due to its capacity to recycle soil $K^+$ (Giacomini *et al*., 2003), storage and transport of assimilates to opening and closure stoms by means of increased $K^+$ in the guard cells, The absorption of water from the cells gards increases the turgidity of the cell to stomatal opening (Kant *et al*., 2005; Rending and Taylor, 1989).

Adequate $K^+$ level of reduces the attack of fungi, bacteria, viruses and nematodes on plants mainly by synthesis of jasmonates and glucosylonates (Datnoff *et al*., 2007; Zörb *et al*., 2014), accumulation of leaf sugars Makes it more palatable for some insects, and bacteria could enter by stomata under $K^+$ starvation (Melotto *et al*., 2006). The absence of $K^+$ in the nutrient solution causes an increase in the rest of cations balancing the ionic content of the cell (Menguel and Kirkby, 1980) also increases of sugars in leaves, and could replacing osmotic molecules (Zörb *et al*., 2014).

Calcium $Ca^{2+}$, is one of the essential elements for plant growth and fruit development (McLaughlin and Wimmer, 1999) and its functions in plant nutrition are well documented (Mengel & Kirkby, 1987; Marschner, 1995; Saure, 2001, Taylor and Locascio, 2004, Villegas *et al*., 2005).

Apical rot (BER) is the common physiological disorder in crops (Frost and Kretchman, 1989). BER worldwide causes losses of up to 50% of production (Taylor and Locascio, 2004). Because BER fruits have significantly less $Ca^{2+}$ than normal fruits, it has been considered that the main cause of BER is a $Ca^{2+}$ shortage in the fruit (Shear, 1975; Adams and Ho, 1993; Wien 1999).

Grower of protected crops systems (shade-house and greenhouse) in Sinaloa, Mexico, use $Ca^{2+}$ higher doses, than crop requirements with nutrient solutions concentrated or unbalanced, so their nutrients can be harmful to the environment, generate pollution by pouring the washing fractions into the soil (Kakuturu *et al*., 2013).

The objective of the present study was to evaluate the effect of different concentrations of $Ca^{2+}$ and $K^+$ on the Nutrient Solution and their interaction on the production of sugars, mineral composition and performance pepper grown in shade.

## 2. Materials and Methods

The average rainfall per year is around 700 mm, precipitation occurring in summer and only 5% in winter. The average annual temperature is 25.9 ℃ that gives a climate classified as BS1 ('h) w (w) (e) according to KOPPEN and modified by García (2004). The soil of the experimental site is classified as chromic vertisol (FAO, 2007), with the following chemical characteristics: table 1. (AOAC, 1998).

Table 1. Effect of $K^+$ and $Ca^{2+}$ interaction on nutrient solution for plant Height (H), Stem Diameter (ST), Total Weight (TW), Leaf Dry Weight (LDW) Stem Dry Weight (SDW)

| pH | MO % | N ppm | P ppm | K ppm | Na ppm | Ca % | Mg % | CIC |
|---|---|---|---|---|---|---|---|---|
| 8.3 | 0.74 | 20.9 | 9.0 | 959 | 586 | 1.14 | 0.19 | 1.2 |

The study was divided in two agricultural cycles, the first one were 9 treatments evaluated and conducted from October 5th, 2014 to May 20th, 2015. After that first experiment, were replicated the secod with the three best treatments from the first experiment, and these were replicated in the 2015-2016 the next agricultural cycle, it was inside a shade house of two acres, located in the facilities of the National Institute of Agricultural Research, in the municipality of Culiacán, México, (24 º63'N and 107 º44'O, and 22 (MASL).

The pepper seed used in both agricultural cycles was "Botaros (1010)" (Zeraim-Geddera) ® variety, germinated in a greenhouse and transplanted 45 days after germination, Nine nutrient solutions at 50% concentration were prepared and applied during the first 15 days after transplanting, and the concentrations were increased to 100% from there to the end of the experiment. Nutrient solutions were adjusted to an osmotic potential of -0.072 Mpa. The concentrations of $K^+$, $Ca^{2+}$ and $Mg^{2+}$ remained constant (Steiner, 1984; Parra-Terraza et al., 2012), maintaining constant concentrations of $NO_3^-$, $H2PO_4^-$ and $SO_4^{2-}$ (Ramírez *et al*., 2010).

Table 2. Effect of $K^+$ and $Ca^{2+}$ interaction on nutrient solution for plant Height (H), Stem Diameter (ST), Total Weight (TW), Leaf Dry Weight (LDW) Stem Dry Weight (SDW)

| Factor | Growth readings at harvest of pepper culture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| %K | | 27 | | | 35 | | | 43 | |
| %Ca | 37 | 45 | 53 | 37 | 45 | 53 | 37 | 45 | 53 |
| H cm | 130$^{ab*}$ | 127$^{ab}$ | 136$^{a}$ | 120$^{ab}$ | 131$^{ab}$ | 115$^{ab}$ | 123$^{ab}$ | 109$^{b}$ | 111$^{ab}$ |
| ST mm | 13.4$^{ab}$ | 13.3$^{ab}$ | 13.6$^{a}$ | 13.1$^{ab}$ | 13.7$^{a}$ | 12.7$^{ab}$ | 13.2$^{ab}$ | 12.8$^{ab}$ | 12.2$^{b}$ |
| TW gr | 77.8$^{a}$ | 69.4$^{ab}$ | 74.0$^{a}$ | 65.7$^{ab}$ | 66.4$^{ab}$ | 70.4$^{ab}$ | 67.3$^{ab}$ | 64.1$^{ab}$ | 58.6$^{b}$ |
| LDW gr | 26.7$^{a}$ | 23.1$^{ab}$ | 22.2$^{ab}$ | 22.4$^{ab}$ | 20.4$^{ab}$ | 26.0$^{a}$ | 21.3$^{ab}$ | 21.5$^{ab}$ | 17.5$^{b}$ |
| SDW gr | 43.0$^{a}$ | 39.3$^{ab}$ | 43.8$^{a}$ | 35.3$^{ab}$ | 38.1$^{ab}$ | 36.2$^{ab}$ | 38.0$^{ab}$ | 34.6$^{ab}$ | 33.1$^{b}$ |

*Within columns means with the same letter are not significantly different (P>0.05).

Nine nutrient solutions were defined, at three levels of %$K^+$ (27, 35, and 43), with three levels of %$Ca^{+2}$ (37, 45, and 53), these nine nutrient solutions were applied simultaneously in four replicates inside the shade house to account as a blocks.

Irrigation was applied every morning at 06:00 am, adjusting the volume of water 35.75% less, than the account for evapotranspiration acordin to Santosh *et al*, (2017). This was calculated by using data from a climatological station of the National Water Commission (A'fifah *et al*., 2015).

The evaluation of growth variables consisted of measuring plant height, stem diameter and leaf area (De Swart *et al*., 2004), Once the growth variables were evaluated, the plants were dissected to partition leaves and stems for chemical analysis and determine the concentration of N, P, K, Ca and Mg, according to the methodologies proposed by Motsara and Roy (2008), these mineral composition were analized at harvest stage. The total of moisture were of 10 plants per treatment on each block, for a total of 360 plants sampled.

Plants were harvested when the fruit reached physiological maturity at 85 days after planting (DAP). The fruits collected were classified for quality as marketable fruits in agreement with USDA (2003), and fruits not meeting adequate quality standards were not included in the yield measurements. Measurements for reducing sugars were determined at two points, 33 ddp and 100 ddp, corresponding to the first cycle and second cycle of flowering, respectively, as described by Gross (1982) and Koch (1996).

The experimental design for grown variables were a block (furrows) with a 3(x)3 factorial arrangement, according to the mineral composition of nine nutrition solitions of three levels of %$K^+$ (27, 35, and 43), with three levels of %$Ca^{+2}$ (37, 45, and 53), these nine nutrient solutions were applied simultaneously as a treatments, the total of plant evaluated for moisture were of 10 plants in four replicates inside the shade house to account as blocks, resulting in a total of 360 plants sampled. The analysis of variance included main factors and interactions with a significance threshold level of $\alpha = 0.05$, was carried out using SAS software were used for the statistical analyses (Statistical Analysis System, version 8.2, SAS Institute, Cary, N.C., USA).

## 3. Results and Discussion

Plant height, stem diameter and total weight showed a larger increase in plants treated with the $K^+/Ca^{2+}$ ratio: 27/53, and the lowest height was recorded in a plant treated with the $K^+/Ca^{2+}$ ratio: 43/45 (Table 2). This indicates that a high potassium dose competes with calcium absorption and therefore retards cell growth and plant development (Ramírez *et al*., 2010). High dose salt concentrations may also explain the slow development since they can cause toxicity (Karimi *et al*., 2009). In the presence of high salt content, the stem diameter and plant weight were observed, indicating stress due to plant competition for nutrients (Zúñiga-Estrada *et al*., 2004).

As shown in Table 3, the nutrient treatment of potassium and calcium at a ratio of 27/53 resulted in plants with the highest growth indicators, confirming the fact that it is not necessary to apply high doses of fertilizer to obtain optimal growth. Parra-Terraza *et al*. (2012) also note that an increase of $Ca^{2+}$ in the nutrient solution is not reflected in production but only in tissue analysis. The mineral content being higher in the treatments whit high dose on agrees with Turkment *et al*. (2008) who reported lower K content in the control that showed the lowest quality of chili plant, independent of the source of potassium (Chapagain *et al*., 2003). Flores *et al*. (2004) report that increasing the concentration of $Ca^{2+}$ in the growth medium increased hydrophilic antioxidante activity in pepper, that are associated with a larger stem diameter. The ratio $K^+/Ca^{2+}$: 27/53 in this work was the treatment of higher content of $CaNO_3$ in proportion to the other treatments.

Table 3. Effect of $K^+$ and $Ca^{2+}$ interaction on nutrient solution for analysis mineral of leaf and stem pepper plants

| Factor | Percentage of nutrient in leaf dry matter | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| %K | 27 | | | 35 | | | 43 | | |
| %Ca | 37 | 45 | 53 | 37 | 45 | 53 | 37 | 45 | 53 |
| %N | 2.22[bc] | 2.29[abc] | 2.29[abc] | 2.32[abc] | 2.52[a] | 2.47[ab] | 2.24[abc] | 2.26[abc] | 2.07[a] |
| %P | 0.52[b] | 0.64[ab] | 0.62[ab] | 0.59[b] | 0.61[ab] | 0.73[a] | 0.53[b] | 0.55[b] | 0.60[ab] |
| %K | 4.49[b] | 4.96[ab] | 5.12[ab] | 4.77[ab] | 4.36[b] | 4.81[ab] | 5.41[a] | 5.09[ab] | 5.36[a] |
| %Mg | 0.86[ab] | 0.92[ab] | 0.99[a] | 0.95[ab] | 0.83[b] | 0.99[a] | 0.90[ab] | 0.94[ab] | 0.88[ab] |
| %Ca | 3.12[ab] | 3.24[ab] | 3.63[a] | 3.59[ab] | 2.96[ab] | 3.27[ab] | 3.05[ab] | 3.28[ab] | 2.95[b] |
| | Percentage of nutrient in dry matter basis of stems | | | | | | | | |
| %N | 0.79[cd] | 0.86[bcd] | 0.86[bcd] | 0.98[ab] | 0.95[bc] | 1.03[a] | 0.92[abc] | 0.86[bcd] | 0.72[c] |
| %P | 0.18[a] | 0.19[a] | 0.24[a] | 0.22[a] | 0.22[a] | 0.31[a] | 0.33[a] | 0.32[a] | 0.24[a] |
| %K | 2.30[a] | 2.27[a] | 2.88[a] | 2.81[a] | 2.54[a] | 3.17[a] | 2.66[a] | 2.93[a] | 2.60[a] |
| %Mg | 0.51[a] | 0.44[a] | 0.59[a] | 0.60[a] | 0.54[a] | 0.56[a] | 0.52[a] | 0.59[a] | 0.55[a] |
| %Ca | 0.95[a] | 0.89[a] | 1.02[a] | 1.06[a] | 1.01[a] | 1.02[a] | 0.95[a] | 1.13[a] | 0.99[a] |

*Within columns means with the same letter are not significantly different (P>0.05).

The fruit yield in the first year was 21-25 fruits per plant. Although there was no statistically significant difference for the number of fruits, it is similar to the studies of Oliveira *et al*., 2013 and Nunes-Júnior *et al*., 2017, who obtained 20 And 24 fruits in their best treatment respectively, the yield was 3.2 - 4.2 kg/plant, that was superior to results obtained by Azofeifa and Moreira (2005) who yielded 2.2 kg/plant (0.35 $m^2$/plant) in similar conditions of management, whereas Oliveira *et al*. (2013) obtained 1.2 kg/plant. The yield data show an increase in second year that is coincident with Parra-Terraza *et al*. (2008), who evaluated different doses of calcium on yield of kg/plant crop in two crop cycles, although in this case there is a significant difference in the $K^+/Ca^{2+}$ ratio: 27/53 in year two, which may be due to the shortening of the treatments to the three best resulting from the first year to the second year. Fruit weight was 143 to 177 g per fruit, which coincides with Zúñiga-Estrada *et al*. (2004) who obtained from 41 to 188 g/fruit, in this respect Oliveira *et al*. (2013) reports a weight 54 g/fruit, as shown in Table 4.

Table 4. Number of sweet pepper fruits an sugar content in leaf, based of $K^+/Ca^{2+}$ relation in the nutritrient solution

| Treatments | production components | | | |
|---|---|---|---|---|
| | Number of fruits per plant | Fruit weight (g) | fruit yield kg/plant | Reducing sugar glucose+fructose g/L |
| Year 1 | | | | |
| 27/37 | 25.5 [a] | 142.6 [a] | 3.62 [a] | 28.3 [d] |
| 27/45 | 23.8 [a] | 147.0 [a] | 3.48 [a] | 27.9 [d] |
| 27/53 | 27.1 [a] | 154.7 [a] | 4.18 [a] | 30.7 [cd] |
| 35/37 | 24.5 [a] | 143.3 [a] | 3.49 [a] | 29.5 [cd] |
| 35/45 | 24.8 [a] | 146.2 [a] | 3.68 [a] | 29.0 [cd] |
| 35/53 | 21.4 [a] | 146.2 [a] | 3.16 [a] | 28.9 [acd] |
| 43/37 | 23.2 [a] | 143.0 [a] | 3.32 [a] | 33.3 [bc] |
| 43/45 | 23.5 [a] | 142.8 [a] | 3.37 [a] | 38.3 [a] |
| 43/53 | 23.1 [a] | 142.0 [a] | 3.27 [a] | 35.8 [ab] |
| Year 2 | | | | |
| 27/37 | 35.5 [a] | 163.7 [a] | 5.82[ab] | 41.3 [a] |
| 27/45 | 37.0 [a] | 168.8 [a] | 6.24[ab] | 38.7 [ab] |
| 27/53 | 39.4 [a] | 177.2 [a] | 6.98 [a] | 36.4 [b] |
| 35/45 | 33.7 [a] | 160.3 [a] | 5.39 [b] | 37.2 [b] |

*Within columns means with the same letter are not significantly different (P>0.05).

Reducing sugars (glucose + fructose) analyzed in plants from year one showed a trend of lower concentration in low doses of $K^+$ throughout the stages of development with values ranging from 28-38 g/L which coincides with Flores *et al* (2004) who obtained values of 29-32 g/L with no significant difference, also the author report a strong relationship of sugars with the production of antioxidants, this trend may be due to producing antioxidants in fruits with more sugar (Lester *et al*., 2010), which means a better use of sugars In the production of fruit (Ramírez *et al*., 2010). In the second year, it was confirmed that the $K^+/Ca^{2+}$ treatment, 27/53, showed the lowest sugar content during the production stage, which coincides with Rolland *et al*. (2006), who mention that sugars play an important role in plant regulatory functions and can accumulate if necessary. The highest fruit yield was obtained by this treatment, indicating that the low dose of potassium is sufficient to obtain the production potential (Nunes-Júnior *et al*., 2017).

The number of marketable fruits evaluated showed only a significant difference in the median size, however, the average fruit weight was 175 g as shown in Table 5. Oliveira *et al*. (2013) reported an average weight of 51 g per fruit, Zúñiga-Estrada *et al*. (2004) reported fruits of Quality 1, which varied from 112 g to 188 g , fruits of Quality 2 varied from 65 to 133 g, and Quality 3, from 41 to 71 g per fruit, respectively.

Table 5. Number of marketable fruits evaluated based on $K^+/Ca^{2+}$ relation on nutritrient solution

| Treatments | Percentage of fruit according to quality | | | |
|---|---|---|---|---|
| | Extra large | Large | Medium | Small |
| | < 250 g. | 200-249 g. | 150-199 g. | > 99 g. |
| Year 1 | | | | |
| 27/37 | 8.0 [a*] | 20.1 [a] | 36.6 [ab] | 35.3 [a] |
| 27/45 | 2.8 [a] | 19.3 [a] | 45.2 [a] | 32.7 [a] |
| 27/53 | 7.5 [a] | 21.2 [a] | 41.3 [ab] | 30.0 [a] |
| 35/37 | 5.7 [a] | 19.0 [a] | 41.3 [ab] | 34.0 [a] |
| 35/45 | 5.7 [a] | 23.1 [a] | 34.5 [ab] | 36.7 [a] |
| 35/53 | 7.6 [a] | 24.3 [a] | 32.4 [b] | 35.7 [a] |
| 43/37 | 4.1 [a] | 20.4 [a] | 36.6 [ab] | 38.9 [a] |
| 43/45 | 6.5 [a] | 18.2 [a] | 35.8 [ab] | 39.5 [a] |
| 43/53 | 5.3 [a] | 19.3 [a] | 37.1 [ab] | 38.3 [a] |
| Year 2 | | | | |
| 27/37 | 10.6 [a] | 25.3 [a] | 36.6 [a] | 27.4 [a] |
| 27/45 | 10.7 [a] | 23.5 [a] | 36.7 [a] | 29.0 [a] |
| 27/53 | 9.1 [a] | 25.5 [a] | 37.0 [a] | 28.3 [a] |
| 35/45 | 10.0 [a] | 24.3 [a] | 36.7 [a] | 29.0 [a] |

*Within columns means with the same letter are not significantly different (P>0.05).

## 4. Conclusions

•Variation of potassium concentrations caused different responses in growth variables, the low dose of potassium was the best, which translates to cost savings on fertilizers. While with calcium, no significant differences were observed in the variables evaluated.

•From the yield measurements, it is deduced that there is higher productivity with the low dose of potassium, compared to that obtained with the control, Steiner solution.

•Analysing reducing sugars could offers a fast, and cheap indicator of the plant's nutritional state but its necesary to continue the experiemnts to achieve beter results.

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**Note:**

**Scope and limitation**

***Scope***. The study covers two macronutrients which affect pepper yield, according with other authors, in particularly the pepper crop yield, soil conditions and sugar measurement. Pepper crop, the most common hybrid used in the zone, specialized for the export trade, which attributes and quality were accepted for the customer, and can used the result for other zones whith Soil system. Yield measurements demonstrate the importance of the crop in the zone of Culiacan, Mexico.

***Limitations***. The study will not cover the other important nutrients as N, Mg, P and S, neither physiology of the plant features such as flowering and root traits. Fertility of soil is an important consideration in any agricultural system. In general we have fertile soils in the primary production areas for chili peppers, thus the response of the plant was only measured by mineral plant analysis and parametric scales. PCR identification of ionic channels activated and their response to calcium and potassium were not considered.