Biostimulation of cucumber crop produced in sheltered conditions

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ABSTRACT

Objective: To evaluate the physiological and productive response of cucumber crop to the induction of three commercial phytohormones (Cito Xplosión, Súper Hormonal, Vitaminum Forte) grown under protected conditions.

Design/methodology/approach: The experiment consisted of three treatments, T1 (Cito Xplosión), T2 (Súper Hormonal), and T3 (Vitaminum Forte). The evaluated variables were plant height, number of leaves, fresh biomass, fruit diameter and length, number and weight, total soluble solids, pH, and electrical conductivity.

Results: In the physiological variables, values of plant heights were 225, 228, 220, and 238 cm for T1, T2, T3, and the control. 33 leaves for all treatments and 31 for the control, T1 and T2 produced higher fresh biomass in leaves, stems, roots, and flowers, while T3 produced higher biomass in fruits. For the fruit length, the values were 16.9, 17.6, 17.6, and 18.4 cm, and diameters of 5.2, 5.2, 5.1, and 5.1 cm for T1, T2, T3, and the control. The weight of fruits was 293.2, 297.3, 283.9, and 281.7 g with yields of 10.1, 10.9, 10.0, and 9.6 kg m^{-2} for T1, T2, T3, and the control.

Limitations on study/implications: More varieties should be evaluated using different nutrient solution concentrations and management practices as a function of the number of stems to assess whether phytohormones influence physiological or productive variables.

Findings/conclusions: From an economic point of view, T2 was the best treatment, achieving a higher yield and fruit quality.

Keywords: phytohormones, growth and development, quality and yield of fruits.

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INTRODUCTION

Cucumber (*Cucumis sativus* L.) is one of the best-known cucurbit vegetables. It is almost grown worldwide, mainly for fresh consumption in an immature state (Barraza-Álvarez, 2015). Cucumber consumption is ranked as the fourth most important vegetable in the world, after tomato (*Solanum lycopersicum* L.), cabbage (*Brassica oleracea* L. var. *capitata*), and onion (*Allium cepa* L.) (Barraza-Álvarez, 2015).

Actually, there are a series of inputs that improve the growth and development of crops, among them are phytohormones, which are natural or synthetic compounds that affect metabolic processes and may improve the productivity and quality of fruits (Gollagi *et al.*, 2019). These compounds are molecules synthesized by the plant that control the vast majority of physiological and biochemical processes such as cell division, growth, and differentiation of aboveground organs and roots (Porta and Jiménez-Nopala, 2019).

The use of phytohormones has made it possible to specifically control processes such as production of secondary metabolites, growth time, reduction of pathogenic agents, fruit ripening induction, and breeding of plant species to improve industrialized products, which are difficult to regulate in a conventional production system (Vega-Celedón *et al.*, 2016).

One of the currently applied tools in agriculture is using phytohormones or plant growth regulators. The application of these compounds modifies plant development to induce thinning, flowering, fruit set, size, and uniform ripening of fruits. The objective of this research was to evaluate the physiological response, production, and biochemical components of cucumber crops with the induction of three commercial plant phytohormones in protected conditions.

MATERIALS AND METHODS

Experiment description

The experiment took place at Colegio de Postgraduados, Montecillo Campus, Estado de Mexico (19° 27’ 58” North latitude and 98° 54’ 58” West longitude, and 2431 m altitude). Seeds of Poinsett 76 variety (indeterminate growth habit) were germinated in expanded polyethylene trays with 200 cavities. They were sown on July 23, transplanted on August 26 until November 25, 2021. The material was grown in a polycarbonate greenhouse under hydroponic system, in black polyethylene bags (12 L) with red tezontle as substrate.

The planting method was the triangular system “tresbolillo” with 40 cm apart from each plant and between lines. They were planted in twin lines (20 m long) with a density of three plants per m^2. Every eight days, lateral shoots were pruned with T-67 pruning shears to keep one-stem plants. The drip irrigation system consisted of a watering line (16 mm diameter) with self-compensated drippers (0.4 m apart), a flow rate of 8 $L\ h^{-1}$, and an operating pressure of 68.64 kPa.

Irrigation

Irrigation was applied with a Steiner (1984) nutrient solution of -0.087 MPa osmotic potential and pH 6.5 throughout the growing season. A flow rate of 0.18 $L\ plant^{-1}\ day^{-1}$ was applied during the first 30 days after transplant, which corresponded to the initial stage, 0.380 L during vegetative stage, 0.50 $L\ plant^{-1}$ in development stage, 0.60 L in production stage (peak demand) and 0.52 L at the end of the season.

Treatment description

Three treatments (T) and a control (CON) were established, which consisted of the application of three commercial phytohormones: T1 (Cito Xplosión®), T2 (Super

Hormonal®), and T3 (Vitaminum Forte®) (AGRONORTECH company) and control without application. The rate applied was 3 mL L^{-1} during the flowering stage, and fruit set; and 5 mL L^{-1} during fruit formation, fruit filling, and beginning of harvest, no application was supplied to the control.

Experimental Design

Each experimental unit was 20 m^2 with 15 plants and 4 replicates and a total area of 80 m^2 per treatment on a randomized complete block design. Treatment mean differences were separated using Tukey least significant difference (LSD) test at $p \leq 0.05$ using MINITAB® release 16 Statistical software.

Response variables

Plant height PH (cm): measured from the base to the apex. Stem diameter SD (cm): measured with a vernier caliper, 1 cm from the base of the plant. Number of leaves per plant. Number of fruits per plant (NFP) during production, number of fruits per plant at physiological maturity. Fresh matter: destructive sampling of plants was carried out. This consisted of extracting the plant from the pot and separating organs (leaves, stems, fruits, and roots). Subsequently, these were weighed fresh and placed in a drying oven (70 °C) for 72 h until constant weight.

Fruit size classification

Four categories were used according to Mexican standard (NMX-FF-023-1982) (Table 1). Fruit length was obtained with a measuring tape (model 32G-8025). The diameter was determined with a vernier (Truper CALDI-6MP).

Biochemical components evaluation

Total soluble solids (TSS): determined from the fruit juice with a Hanna model HI96801 refractometer and expressed in °Brix. Fruit firmness was measured with a FDV30 texturometer (Greenwich, CT 06836, USA), recording the skin resistance to puncture and expressed in newtons (N). The pH and electrical conductivity (EC) were directly determined in the fruit juice (Hanna instruments-model HI98130), the EC values were expressed in dS m^{-1}.

RESULTS AND DISCUSSION

Evaluation of physiological variables

Plant height

Figure 1 shows that growth slowly begins until 30 days after transplant (DAT). Subsequently, at 37 and 51 DAT, development noticeably increased in all treatments until reaching a height of 116, 115, 112, and 98 cm for T1, T2, T3, and control (Figure 1). At 58 DAT, due to the effect of the phytohormones, it was observed that plants regulated their growth speed since a part of their energy was translocated to flowering, pollination, and fruit set. The opposite occurred in the control treatment, as the plant used its energy in growth, regardless of fruit production.

Table 1. Size classification of cucumber fruits according to Mexican standard.

Quality	Diameter (cm)	Length (cm)
Big	>6.5	>16.5
Medium	5.1-6.5	15.1- 16.5
Small	3.5- 5.0	14.0- 15.0
Lag	>3.4	>14.0

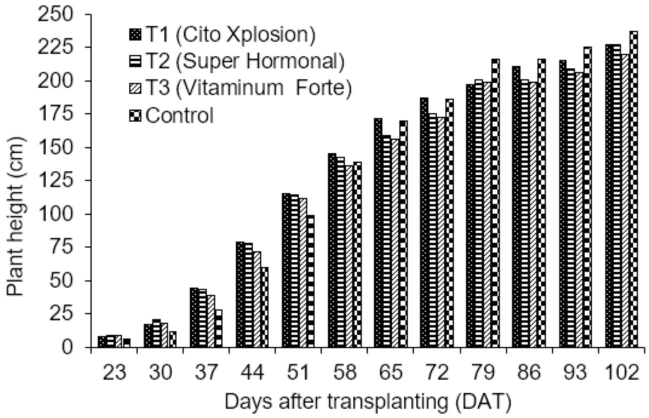

Figure 1. Plant height for evaluated treatments.

The maximum height was 227, 228, 220, and 238 cm for T1, T2, T3, and control (Figure 1). Furthermore, at 65 DAT, control treatments significantly began to accelerate its growth compared to the rest of the treatments. The values reported here are higher than those reported by Gabriel-Ortega *et al.* (2022) who found 161-80 cm height due to the application of different types of biostimulants in cucumber crops grown under greenhouse conditions.

The phytohormones applied in all treatments were statistically significant ($p \leq 0.05$) in the variables of fruit weight, yield, firmness, and fruit diameter. However, in plant height, no statistical difference was found between the treatments compared to the control (Figure 1).

Stem diameter and number of leaves

There were no significant differences between the treatments ($p \geq 0.05$) with respect to stem diameter. The results in this research were on average of 1.1 cm, which agree with those reported by Ayala-Tafoya *et al.* (2019) who found a stem diameter of 1.07 cm in cucumber plants “Alanis RZ F1” variety planted at a density of 1.68 plants m^2 and pruned to one stem per plant. Gabriel-Ortega *et al.* (2022) reported a 0.98 cm stem diameter in the variety “Intimator”. This morphological trait has shown greater genetic propensity since Ortiz *et al.* (2009) reported differences in stem diameter (0.61 - 0.77 cm) between cucumber varieties.

33 leaves per plant were obtained in the three treatments and 31 leaves in the control, with no significant differences due to application of phytohormones. Ayala-Tafoya *et al.* (2019) reported 41 total leaves and 260 cm height in a cucumber crop grown in a greenhouse. The number of leaves is directly related to the leaf area. Therefore, they are important parameters in plant growth evaluation and their determination is essential for the correct interpretation of physiological processes in plants (Mendoza-Pérez *et al.*, 2018b; Ayala-Tafoya *et al.*, 2019).

Fresh biomass

The importance of evaluating fresh biomass in plants relies on the quantitative determination of water content (González *et al.*, 2018). A similar accumulation was obtained in all treatments compared to the control during the initial stage. However, starting at 51 days after transplant (DAT), the fresh biomass accumulated in leaves, stems and roots started to increase. At 72 DAT, fruit production increased in all treatments along with the control, which corresponded to the stage that harvest began.

The performance of the three treatments was similar (Figure 2). Furthermore, it is important to know this variable because it can serve as a tool in irrigation and fertilization

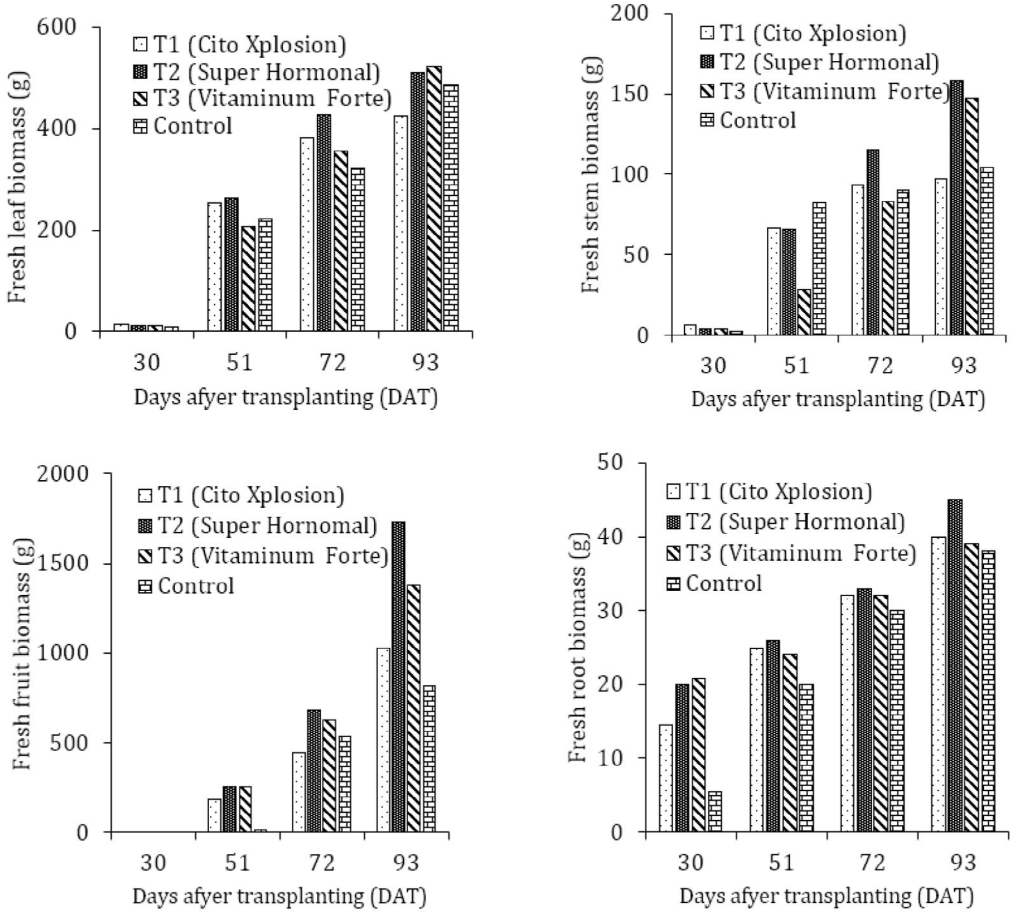

Figure 2. Fresh biomass accumulation in plant organs of all treatments.

scheduling on this crop. In the case of fruits (Figure 2), at 51 DAT the fresh biomass accumulation started to increase in all treatments including the control.

Physical characteristics and fruit yield

Fruit length

The length and diameter variables of fruits are components related to quality attributed to the size and fruit appearance. These are the most important parameters considered when classifying the size of the fruits for export. In this research, values of 16.9, 17.6, 17.6, and 18.4 cm in length were found for T1, T2, T3, and control respectively, with no significant differences due to the phytohormones. This response was also found in fruit diameter. Montaño *et al.* (2018) reported a value of 17.5 cm in cucumber fruit, cultivar Poisentt 76.

Fruit diameter

In this research, fruit diameters of 5.2, 5.2, 5.1, and 5.1 cm were found for T1, T2, T3, and control respectively. Montaño *et al.* (2018) reported a fruit width of 5.0 and 6.0 cm in Poisentt 76 cultivar, while López-Elías *et al.* (2011b) reported 5.0 cm diameter. Therefore, the values reported here are within the established range of 5.0 cm for American-type cucumber. A positive effect was found in this variable, given that treatments with applied phytohormones increased fruit diameter (1 cm) compared to the control treatment. According to various researchers, fruit diameter ranges between 4.3 and 5.3 cm for large cucumbers. Westwood cited by Montaño and Méndez (2009) pointed out that fruit width depended on other parameters such as the cortical area, pulp, and central cavity.

Average fruit weight

The average weight of cucumber fruits is presented in Table 2. T2 (Super hormonal®) presented the highest numerical value (297.3 g) compared to the rest of the treatments. Montaño (2018) obtained a similar results (293 and 317 g) average weight of cucumber fruits in Poinsett 76 cultivar. Chacón *et al.* (2017) reported weights of 224-239 g for three cucumber genotypes grown in greenhouse conditions. Chacón-Padilla and Monge-Pérez (2020) reported a fruit weight of 278 g, while Sánchez del Castillo *et al.* (2014) reported 270 g in Alcázar cultivar grown in hydroponic system.

Table 2. Stem diameter, number of leaves, length, and fruit diameter.

Treatments	NF m^2	FD (cm)	FL (cm)	MWF (g)	FY ($kg\ m^{-2}$)
T1 (Cito Xplosión)	36	5.2 a	16.9 a	293.2 b	10.1 b
T2 (Súper Hormonal)	36	5.2 a	17.6 a	297.3 a	10.9 a
T3 (Vitaminum Forte)	36	5.1 a	17.6 a	283.9 c	10.0 b
Control	33	5.1 a	18.4 a	281.7 d	9.6 c

Columns with distinct letters are statistically different. Fisher/Tukey Mean Separation Test ($P<0.05$). NF: number of fruits, FD; fruit diameter, FL; fruit length, MWF; medium weight of fruits, FY; Fruit yield.

Number of fruits

No statistical difference was found in the number of fruits per plant due to application of phytohormones in all treatments. Sánchez del Castillo *et al.* (2014) reported 38.5 fruits m^2 in Alcázar cultivar with a density of 6 plants m^2 grown in a greenhouse in different hydroponic systems.

Golabadi *et al.* (2013) reported that the number of cucumber fruits per plant projects the greatest positive effect on the total production, indicating that this parameter is one of the most reliable components for selecting genotypes with high fruit yield. Chacón-Padilla and Monge-Pérez (2020) reported 18.83 fruits per plant and mentioned that large sized fruits reached a greater length and fruit weight, taking approximately 15 days to develop each fruit. Therefore, larger size reduced the plants' ability to produce a greater number of fruits per plant.

Fruit yield

Values of 10.1, 10.9, 10.0, and 9.6 kg m^{-2} for fruit yield were obtained for T1, T2, T3, and control respectively. These results demonstrate that the correct use and application of plant phytohormones in peak demand stages of cucumber cultivar can be a viable alternative to improve fruit quality and yield. Chacón-Padilla and Monge-Pérez (2020) reported similar yield of 8.7 kg per plant. According to the results obtained in this research, a balanced concentration of the nutrient solution and the application of biostimulants in stages of maximum water and nutrient demand can be the key to improving the growth processes, development, and formation of organs, quality, and fruit yield.

Fruit size classification

In the fruit size by length classification, the control treatment showed higher values (84, 2, 11, and 2% large fruit, medium, small, and lagging fruit), while T2 (Super hormonal®) had fruits of 82, 6, 12 and 0% large, medium, small and lag respectively.

Regarding its diameter, T1 (Cito Xplosión®) had the highest value of 7, 52, 41, and 0% large, medium, small, and lag fruits. The effect of applying phytohormones in the treatments increased the harvested fruit diameter compared to the control. The results found in this research coincide with those reported by Reyes-Pérez *et al.* (2019) who found significant differences in polar and equatorial diameter in Hybrid SARIG 454 with the application of chitosan biostimulant (200 mg ha^{-1}).

Biochemical components

The firmness variable was significantly different in all treatments. T3 (Vitaminum Forte®) had the highest value of 6.2 N. This treatment accumulated less fresh matter which was mainly attributed to the lower biostimulant concentration. In the case of the soluble solids, no significant differences were found between the treatments. However, numerically, T3 (Vitaminum Forte®) was the highest with 6.2 °Brix. Cucumbers are non-climacteric fruits characterized by low total soluble solids, so the sugar accumulation during the growth and maturity stage does not experience significant changes. Moreno-Velázquez *et al.* (2013)

reported values of 3.75 °Brix for Zapata cultivar, 3.47 for Lider cultivar and 2.95 °Brix for Constable cultivars.

The pH values in fruit juice were 4.9, 4.2, 5.3, and 5.2 for T1, T2, T3, and control respectively (Table 3). Moreno-Velázquez *et al.* (2013) reported higher pH values (5.64) for Zapata cultivar, 5.94 for Lider and 5.6 for Constable cultivar). The pH is a measure of H+ ions concentration in any aqueous solution. Therefore, low pH values indicate a higher concentration of H+ ions and vice versa. Regarding the EC variable, T1 presented the highest value (3.0 dS m^{-1}).

Table 3. Biochemical components in cucumber fruit juice.

Treatments	Firmness (N)	°Brix	pH	Electrical conductivity (dS m^{-1})
T1 (Cito Xplosión)	4.8 b	5.8 a	4.9 b	3.0 a
T2 (Súper Hormonal)	4.4 c	6.0 a	4.2 b	2.9 b
T3 (Vitaminum Forte)	6.2 a	6.2 a	5.3 a	2.4 c
Control	4.1 c	6.1 a	5.2 a	2.9 b

Columns with distinct letters are statistically different. Fisher/Tukey Mean Separation Test ($P<0.05$).

CONCLUSIONS

The exogenous application of biostimulants had a positive effect on the vegetative development of plants and promoted the increase in morphological characteristics of the fruits, such as diameter, firmness, and weight. In biochemical components, biostimulants favored the total soluble solids accumulation. It is important to note that biostimulant induction in crops during key phenological stages substantially increases the plants' capacity to carry out photosynthesis, water, and nutrient uptake. With this technique, the yield and quality of crop fruits increase, contributing to the growers' economy and the population's nutrition.

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