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Increasing greenhouse cucumber growth and yield with nano calcium and silicon

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Abstract

Trials were carried out in plastic greenhouses at a private farm in the Qaha region, Qalubia Governorate, Egypt (30.288 N; 31.198 E), during two consecutive spring seasons (2020 and 2021). The objective was to investigate the impact of nano compounds, spray specifically nano calcium and nano silicon, on the growth characteristics, yield, and quality of cucumber plants (*Cucumis sativus* L.) under protected cultivation conditions. The study used two foliar sprays of Lithovit® (nano calcium carbonate 80.2 %) at 0.0, 0.25, 0.5, and 1.0 g/L and nano silicon (SiO_2 25 %) at 0.0, 0.5, 1.0, and 1.5 mL/L. Nano elements (calcium or silicon) were applied to cucumber seedlings in the second, fourth, sixth, and eighth weeks after transplantation. All monitored attributes increased with both nano-element treatments. Plants receiving nano calcium had higher plant height, fresh and dry weights, and branch counts than those receiving nano silicon. However, growth was best with 1.0 g/L nano calcium. Compared to control, nano elements boosted cucumber plant N, P, K, Ca, and Si. In both nano calcium and nano silicon treatments, fruit length, diameter, average weight, and total weight rose. Yield increases may outweigh nano nutrient costs.

Key words: Cucumber, nano calcium, nano silicon, plant growth, total fruit weight

Introduction

The cucumber crop holds great importance in today's horticulture industry due to its high nutritional value and significant economic value. Due to its abundance of vitamins, minerals, and antioxidants, it serves as a crucial element in one's diet. Cucumbers were grown on approximately 3.1 million hectares globally, with an estimated 77.2 million metric tonnes production in 2020 (F.A.O.S.T.A.T., 2020). Cucumber open-field production faces a number of challenges (Eifediyi and Remison, 2010). Susceptibility to diseases caused by soil-borne pathogens, pests, and adverse environmental conditions such as temperature fluctuations and excessive rain are examples of these. This lowers the quality of the produce, especially that destined for export. Furthermore, open-field cultivation necessitates a large amount of water and increases the risks of pesticide residues, soil erosion, and nutrient leaching, all of which impact crop quality and yield. The transition to greenhouse conditions can overcome all of these challenges and disadvantages. Higher plant growth, production, and quality, as well as higher use efficiency of production inputs, are obtained with the ability to control growth conditions in the greenhouse. However, continuous improvement in those growth conditions is still required to improve plant production and quality even further. Nanotechnology has the potential to make a significant contribution to this field.

Nanotechnology is a new scientific technique that refers to materials with a scale of 100 nanometers or less (Otles and Yalcin, 2013). Agricultural researchers have begun to use it in the breeding of new crop varieties, the development of new functional materials and smart delivery systems for agrochemicals such as pesticides and fertilisers, smart systems for food processing integration, packaging, and other areas such as pesticide and herbicide residue remediation from plant and soil, water effluent treatment, and so on (Moraru *et al.*, 2003).

Nanotechnology can help increase agricultural product value and solve environmental issues. Controlled or delayed-release fertilisers can be made using nanoparticles and nanopowders. More surface area or density of reactive areas on nanoparticles and an increase in the reactivity of these areas on particle surfaces contribute to their high reactivity (Ditta, 2012; Grover *et al.*, 2012; and Abd El-baset, 2018). These characteristics facilitate the absorption of nanoscale fertilisers and pesticides. Because of its small size, a nanomaterial has distinct property characteristics; thus, its physicochemical properties can differ from those of its bulk counterpart, resulting in greater solubility and surface reactivity (Castiglione and Cremonini, 2009) demonstrated the Beneficial effect of nano calcium on plant growth parameters and yield of on tomatoes (Tantawy *et al.*, 2014; and Sajyan *et al.*, 2018), on snap bean Hamoda, (2016), and on green bean Gomaa (2017) has been reported. Furthermore, the use of nano silicon on some vegetable crops increased plant growth, chemical composition, and yield. Tantawy *et al.* (2015) on sweet pepper and Gomaa (2017) on green bean found similar results. However, none of those nanonutrients mentioned above have been tested in the Cucurbitaceae family, particularly in the cucumber. Furthermore, the potential benefits of these nutrients have yet to be weighed against the additional costs associated with their implementation. As a result, this study aims to investigate the responses of cucumber plants' growth, production, and fruit attributes to the application of nano-calcium and nano-silicon.

Materials and methods

Two experiments were carried out under plastic greenhouses at a private farm in Qaha region, Qalubia Governorate (30.288 N; 31.198 E), during the two successive spring seasons of 2020 and

2021 to study the effect of spraying nano compounds on growth, yield, and yield quality of cucumber plants grown under protected culture conditions.

Greenhouse and plant material: Cucumber (*Cucumis sativus* L.) seeds hybrid Reema®, a well-known hybrid recommended for spring and late summer greenhouse cultivations in the Middle East, were sown in seedling trays (84 cells) on February 1st. and transplanted in plastic greenhouse on February 25th in both seasons.

The plastic greenhouse measures 6 x 40 x 3.5 m (W x L x H). Using standard methods, composite samples of greenhouse soil (0-30 cm depth) were taken before cucumber seedlings were transplanted. The samples were analyzed at the Soil, Water and Environment Research Institute (Mansoura governorate), Agriculture Research Center. The chemical properties of the soil were determined using the methods described in Association of Official Agriculture Chemists (A.O.A.C., 2019). The physical and chemical analyses of the experimental soil under this investigation are shown in Table 1. The plastic greenhouse area consisted of four 1 x 38 m ridges each. Two rows of plants were transplanted on each ridge. Cucumber seedlings with three true leaves (25 days old) were transplanted in the greenhouse. The distance between plants was 50 cm apart, with a plant density of 2.2 plants.m^{-2}. Plants were turned vertically by braiding the main stem with a vertical suspended polyethylene twine piece from a horizontal, overhead support wire 2.0 m above the plant rows. Standard agricultural practices regarding drip irrigation, fertilization, disease control, and pest control were applied according to the recommendations of the Ministry of Agriculture.

Nano compounds foliar treatments: Two compounds were used to make aqueous solutions with different concentrations. The two compounds are Nano calcium contains calcium carbonate (80.2 %), magnesium carbonate (4.6 %), and iron (0.75 %) by commercially named Lithovit® whereas, nano silicon contains (Nano-SiO_2 25 %). Nano elements (calcium and silicon) treatments were sprayed on cucumber plants in the 2nd, 4th, 6th, and 8th week after transplanting.

Seven different treatments were applied as follows:

Nano calcium at a rate of 0.25 g L^{-1} water.
Nano calcium at a rate of 0.5 g L^{-1} water.
Nano calcium at a rate of 1.0 g L^{-1} water.
Nano silicon at a rate of 0.5 cm^3 L^{-1} water.
Nano silicon at a rate of 1.0 cm^3 L^{-1} water.
Nano silicon at a rate of 1.5 cm^3 L^{-1} water.
Control (treated with tap water) (0.0 nano compound).

Plant growth characteristics: Four random plants from each plot were taken at the end of each season and the following measurements were recorded:

Vegetative characteristics: All vegetative characteristics such as plant height, number of branches per plant, and fresh and dry weights per plant were measured by the end of both seasons.

Chemical characteristics: Macro and micronutrient contents: Samples of fresh leaves (the 6th leaf from the plant top) were taken at 70 days from transplanting, and considered the most representative ones for plant analysis, according to Ward (1963).

Table 1. Physical and chemical characteristics of plastic greenhouses soil in 2020 and 2021 seasons.

Soil properties	Season	
	2020	2021
Physical analysis:		
Sand (%)	22.00	21.50
Silt (%)	24.00	24.50
Clay (%)	54.00	55.00
Soil Texture	Clay	Clay
Chemical analysis:		
pH	8.12	8.32
E.C. (mM / cm)	1.36	1.44
Organic matter (%)	2.21	2.33
Soluble cations (meq/100 g soil)		
Na^+	6.57	6.86
Ca^{++}	0.55	0.66
Mg^{++}	0.41	0.40
K^+	0.10	0.12
Soluble anions (meq/100 g soil)		
Cl^-	1.41	1.65
HCO_3^-	1.30	1.60
SO_4^{--}	4.92	4.79
Available elements		
N (ppm)	28.35	29.33
P (ppm)	10.00	11.00
K (ppm)	100.00	105.00

The leaves were oven-dried at 70 ºC till a constant weight was reached. The dry matter was finely ground and wet digested with H_2O_2 and concentrated H_2SO_4 for the determination of nitrogen, phosphorus, potassium, calcium, and silicon according to the following methods: Nitrogen was determined using the Micro-Kjeldahl method Piper, (1947); phosphorus was determined calorimetrically as described by King, (1951); potassium and calcium were determined using the Flame photometer according to Jackson, (1967). Silicon was chemically analyzed and measured in leaves by Flame-photometer set as described by Brown, and Lilleland, (1946). Total chlorophyll content was measured in the leaves (the 4th leaf from the plant top) using the Minolta SPAD 501 chlorophyll meter (Yadava, 1986).

Fruit characteristics: During the third picking, three random samples were taken from each experimental unit to measure the length (cm), diameter (cm), and average weight (g) of individual fruits. Total fruit weight/plant (kg) was considered as total fruit yield for picks during the harvesting period.

Experimental design and statistical analysis: Combined analysis of the two seasons was carried out using randomized complete block design (R.C.B.) with three replicates and different means of treatments were compared using the Least Significant Difference test (LSD) at *P*=0.05 probability level (Snedecor and Cochran, 1991).

Results

Vegetative characteristics: According to Table (2), all applied nano-elements (calcium or silicon) resulted in positive and significant changes in plant height, fresh and dry weights, and number of branches per plant. Additionally, plants receiving nano calcium had higher values than those receiving nano silicon.

However, using a solution with a concentration of 1.0 g L^{-1} of nano calcium had the best positive effect on the height, fresh and dry weights, and number of branches of the plant compared to all other treatments. The treatment of 1.5 cm^3 L^{-1} of nano silicon was the second-best option. The smallest positive change was seen when using the lowest concentrations of nano calcium (0. 25 g L^{-1}) and nano silicon (0. 5 cm^3 L^{-1}). In contrast, cucumber plants treated with tap water (control) had the lowest values for the abovementioned traits. These findings were consistent during both seasons.

Biochemical characteristics: The data in Table 3 demonstrates that the utilization of nano calcium or silicon led to a significant boost in nitrogen, phosphorus, potassium, total chlorophyll content, calcium, and silicon in cucumber plants when compared to the control. Additionally, the highest amounts of nitrogen, phosphorus, potassium, total chlorophyll content, and calcium percentages were found in plants treated with nano calcium at a concentration of 1.0 g L^{-1}. This was followed by plants treated with nano silicon at a rate of 1.5 cm^3 L^{-1} in descending order. However, the later treatment of nano silicon had the most silicon content, followed by plants supplied with nano calcium with a concentration of 1.0 g L^{-1}. The smallest positive result was seen when the lowest concentrations of calcium and silicon were used. On the other hand, the cucumber plants in the control group (treated with tap water) had the lowest levels of nitrogen, phosphorus, potassium, chlorophyll, calcium, and silicon. This was observed in both experimental seasons.

Fruit characteristics: According to the data in Table 4, it can be observed that the application of nano calcium and nano silicon sprays has a substantial effect on the size and weight of cucumber fruits. The results demonstrate that spraying these compounds at any rate led to a significant enhancement in the length, diameter, average weight, and total weight of the fruits compared to the control treatment. In summary, the utilization of nano calcium and nano silicon sprays significantly boosted the size and weight of cucumber fruits. In addition, nano calcium at 1.0 g L-1 gave the best results for fruit length, diameter, average fruit weight, and total fruit weight per plant. This was followed by plants treated with nano silicon at a concentration of 1.5 cm L^{-1}, in decreasing order. The smallest positive impact was found when using the lowest concentration, specifically 0. 25 g L^{-1} of nano calcium and 0.5 cm L^{-1} of nano silicon. In contrast, the control plants had the lowest scores in the abovementioned traits. The results mentioned above are very similar in both seasons 2020 and 2021.

Discussion

In this study, the application of nano compounds, specifically nano calcium and nano silicon, exhibited stimulant affects on various growth aspects of cucumber plants. These positive effects can be attributed to the significant roles that calcium and silicon play in numerous plant physiological processes, influencing overall plant growth and production. As a crucial macro essential nutrient, Nano calcium contributes to key biological processes such as cell wall formation, cell division, elongation, enzyme activation, and nutrient uptake (Van Goer, 1996; Morard *et al.*, 1996). The taller plants and longer fruits observed in our study may result from calcium's vital role in maintaining plant cell wall integrity and stability (Ashraf, 2004), contributing to the overall structural strength of the plant.

Table 2. Effect of nano calcium and silicon on height, fresh weight, dry weight, and number of branches per cucumber plant under greenhouse conditions during the two seasons of 2020 and 2021

Treatments	height (cm)	Fresh weight (g)	Dry weight (g)	Number of branches
2020 Season				
Nano Ca 0.25 g L^{-1}	215.54	258.24	42.71	12.01
Nano Ca 0.5 g L^{-1}	228.03	273.07	50.45	13.06
Nano Ca 1 g L^{-1}	241.25	288.27	54.90	14.52
Nano Si 0.5 cm L^{-1}	212.45	254.33	39.49	12.41
Nano Si 1 cm L^{-1}	226.43	268.12	46.22	13.71
Nano Si 1.5 cm L^{-1}	236.54	270.06	49.48	13.90
Control	197.33	234.90	27.50	07.04
LSD at P=0.05	5.12	6.18	2.02	1.63
2021 Season				
Nano Ca 0.25 g L^{-1}	213.70	257.53	39.77	12.41
Nano Ca 0.5 g L^{-1}	226.70	269.23	49.38	13.29
Nano Ca 1 g L^{-1}	238.21	283.72	53.69	15.11
Nano Si 0.5 cm L^{-1}	212.11	252.23	37.38	12.41
Nano Si 1 cm L^{-1}	225.20	269.52	44.22	14.08
Nano Si 1.5 cm L^{-1}	234.43	281.12	48.37	14.71
Control	199.10	237.19	25.49	07.50
LSD at P=0.05	5.06	6.04	1.89	1.51

Table 3. Effect of nano calcium and Silicon applications on nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), silicon (Si), and chlorophyll contents of cucumber leaves under greenhouse conditions during the two seasons of 2020 and 2021

Treatments	N (%)	P (%)	K (%)	Ca (%)	Si (%)	Chlorophyll (SPAD)
2020 Season						
Nano Ca 0.25 g L^{-1}	1.81	0.625	2.61	3.68	2.22	48.69
Nano Ca 0.5 g L^{-1}	2.08	0.841	3.15	4.09	2.84	50.45
Nano Ca 1 g L^{-1}	2.45	0.923	3.42	4.37	3.10	51.92
Nano Si 0.5 cm L^{-1}	1.84	0.601	2.50	3.35	2.30	47.71
Nano Si 1 cm L^{-1}	2.07	0.742	2.85	3.41	2.94	48.49
Nano Si 1.5 cm L^{-1}	2.21	0.825	3.50	3.53	3.28	50.02
Control	1.71	0.420	2.23	3.24	1.70	44.18
LSD at P=0.05	0.20	0.07	0.19	0.16	0.20	0.45
2021 Season						
Nano Ca 0.25 g L^{-1}	1.87	0.613	2.73	3.44	2.20	46.35
Nano Ca 0.5 g L^{-1}	2.10	0.822	3.17	4.06	2.81	48.11
Nano Ca 1 g L^{-1}	2.31	0.927	3.56	4.30	3.01	59.68
Nano Si 0.5 cm L^{-1}	1.77	0.600	2.62	3.25	2.19	45.09
Nano Si 1 cm L^{-1}	2.06	0.732	2.86	3.29	2.83	46.21
Nano Si 1.5 cm L^{-1}	2.16	0.822	3.42	3.43	3.10	48.41
Control	1.71	0.481	2.27	3.18	1.62	43.71
LSD at P=0.05	0.17	0.05	0.25	0.14	0.19	0.40

Furthermore, calcium acts as a signaling molecule in regulating stomatal movement and nutrient transport, influencing plant water status and photosynthesis (Marschner, 1995). Our study's higher fresh weight and nutrient contents align with these explanations. In contrast, the improved growth and productivity observed with nano silicon addition may be attributed to its effects on increasing root mass and volume, leading to expanded total and adsorbing root surfaces (Matichenkov, 1996) and enhanced root respiration (Yamaguchi *et al.*, 1995). Silicon's positive impact on chlorophyll concentration per unit leaf area (Aleshin, 1982) results in higher

Table 4. Effect of nano calcium and nano silicon on length, diameter, average weight, and total weight of cucumber fruit under greenhouse conditions during the two seasons of 2020 and 2021

Treatments	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Total fruit weight / plant (kg)
2020 Season				
Nano Ca 0.25 g L^{-1}	13.51	3.71	123.52	3.61
Nano Ca 0.5 g L^{-1}	14.69	4.05	133.61	4.02
Nano Ca 1 g L^{-1}	15.19	4.71	145.59	4.54
Nano Si 0.5 cm L^{-1}	12.74	3.44	121.60	3.34
Nano Si 1 cm L^{-1}	14.29	3.81	132.01	3.82
Nano Si 1.5 cm L^{-1}	14.68	4.19	140.31	4.30
Control	11.01	2.81	103.10	2.51
LSD at 0.05	0.37	0.25	5.10	0.17
2021 Season				
Nano Ca 0.25 g L^{-1}	13.36	3.51	122.29	3.61
Nano Ca 0.5 g L^{-1}	14.47	3.84	131.21	4.17
Nano Ca 1 g L^{-1}	15.25	4.72	144.51	4.54
Nano Si 0.5 cm L^{-1}	12.51	3.41	120.49	3.30
Nano Si 1 cm L^{-1}	13.84	3.82	131.39	3.84
Nano Si 1.5 cm L^{-1}	14.51	4.18	138.81	4.25
Control	11.45	2.61	103.42	2.63
LSD at 0.05	0.40	0.20	4.51	0.21

light use efficiency, as supported by Anser *et al.* (2012), who found increased chlorophyll content, stomatal conductance, and photosynthesis with silicon amendment.

The enhanced dry weight observed in our study may be explained by silicon's role in increasing concentrations of the enzyme ribulose bisphosphate carboxylase in leaf tissue (Adatia and Besford, 1986), regulating CO_2 metabolism for more efficient plant use. Silicon also contributes to improved plant water status, enhanced photosynthetic activity, and maintenance of leaf organelle ultrastructure (Romero *et al.*, 2006; Shu and Liu, 2001), which is ultimately reflected in higher plant fresh weight.

The study suggests that the superiority of nano calcium carbonate, commercialized as Lithovit®, in promoting plant growth and total yield can be attributed to its role as a source of calcium and carbonate. The latter increases within plants, forming carbon dioxide, which accumulates in cells, enhancing the assimilation of photosynthetic products and consequently boosting vegetative growth. Similar results were reported by Abo Sedera *et al.* (2015) and El-Atabany (2015).

While our study indicates positive impacts for both nano nutrients' applied concentrations, certain considerations need attention. The treatments were implemented during a specific growing season, suggesting possible growing season interaction effects on applied concentrations that warrant further investigation. Additionally, the persistence of observed positive effects at higher concentrations beyond the applied treatments and potential antagonistic or determinate effects on other vital nutrients, affecting fruit production and quality, require further exploration.

In summary, the application of nano calcium and nano silicon significantly enhanced various growth aspects of cucumber plants, with nano calcium, especially at 1.0 g L^{-1}, demonstrating superior effects. The study suggests that nano calcium carbonate (Lithovit®) effectively promotes plant growth. Further research is needed to explore seasonal variations, the persistence of effects at higher concentrations, and potential impacts on other nutrients for practical agricultural applications.

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