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Growth and Yield of Cucumber (*Cucumis sativus* L.) under Water Stress in Shade Net Conditions through Kaolin and Chitosan Applications

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ABSTRACT

Objective: To evaluate the effect of kaolin and chitosan as agronomic tools for mitigating water stress on the growth and yield of Persian cucumber (*Cucumis sativus* L.) under protected cultivation conditions.

Design/Methodology/Approach: The Persian cucumber variety was cultivated under shade netting, and five treatments were established using different doses of kaolin (30 and 50 g L^{-1} of water) and chitosan (3.5- and 5-mL L^{-1} of water), along with a control treatment (without application). These treatments were assessed under two periods of water stress, defined as the point at which 80% of the total available water in the soil had been depleted. A randomized complete block design was employed, with four replicates and five plants per experimental unit.

Results: With regard to growth, the treatments had no significant effect on plant height or stem diameter. However, a marked effect was observed on crop yield, with the control treatment recording the lowest value at 12.9 t ha^{-1}, whereas the most effective treatment corresponded to the application of chitosan at a dose of 3.5 mL L^{-1} of water, achieving a yield of 25.2 t ha^{-1}.

Limitations of the Study/Implications: No limitations were identified in the present study.

Findings/Conclusions: Chitosan and kaolin exert a positive influence on the growth and development of cucumber fruit under shade net conditions, thereby enhancing yield under water stress conditions.

Keywords: protected agriculture, drought, sustainability.

INTRODUCTION

Changes in the spatial and temporal distribution of precipitation have led to water deficits in the soils of agroecosystems, particularly affecting the arid and semi-arid regions of Mexico, where agriculture depends heavily on water storage in reservoirs (Rentería and Hanson, 2025). Water stress is one of the most severe abiotic stress factors, adversely

affecting crop growth and development and constraining agricultural production in arid and semi-arid zones, thereby jeopardizing food security (Kadir *et al.*, 2024). In view of the above, there is an urgent need to identify alternatives capable of protecting crops from harsh climatic conditions, such as drought or deficit irrigation, which induce water stress (Kadir *et al.*, 2024; Faghihi *et al.*, 2025). One strategy to reduce the detrimental effects of abiotic stress on plants and enhance crop performance involves the application of biostimulants. These elicitors comprise chemical compounds or biological factors capable of inducing physiological modifications in plants. Among the various compounds identified, chitosan stands out because of its eliciting properties, as it activates plant responses to stress and strengthens their defense mechanisms (Kadir *et al.*, 2024). Chitosan is recognized as a highly relevant biopolymer in agriculture, as it is used as a controlled-release fertilizer, plant growth stimulant and promoter, disease-suppressive agent with antimicrobial properties, mitigator of biotic and abiotic stress, seed treatment, and soil amendment. In addition, it exerts beneficial effects on fruits and vegetables during postharvest, among other applications (Sreelakshmi *et al.*, 2024). According to Hidangmayum *et al.* (2023), chitosan application mitigates the harmful effects of water stress by activating the antioxidant system, increasing relative water content, and improving photosynthetic activity.

Kaolin is an antitranspirant compound that has been widely used in recent years as a safe material in organic agriculture. Its most notable characteristic is its white color and its ability to reflect light reaching the leaf surface, thereby reducing plant thermal load and increasing productivity (Faghihi *et al.*, 2025). Kaolin can act as a mitigating factor to reduce water stress. This compound, an aluminum phyllosilicate, forms a thin film of nanoparticles when applied foliarly, promoting leaf chemical composition, plant water status, and photosynthesis-related activities (AbuEl-Leil *et al.*, 2024).

In Mexico, and particularly in Sinaloa, cucumber (*Cucumis sativus* L.) is a vegetable crop of considerable economic importance, contributing significantly to national production. During the 2020-2024 period, the cultivated area of this cucurbit reached 16,019 ha, with an average production volume of 1,004,510 t. Of this area, 21.8% was established in the state of Sinaloa, which accounted for 29.6% of national production of this fruit. Furthermore, the area cultivated under shade net conditions amounted to 3,246 ha nationwide, with an average production of 359,210 t during the same period. Sinaloa contributed 41% of the national area under this technology and accounted for 39.1% of its production (SIAP, 2025). In light of the foregoing, the effect of kaolin and chitosan as inputs for mitigating water stress on the growth and production of Persian cucumber (*Cucumis sativus* L.) under protected conditions was evaluated.

MATERIALS AND METHODS

The research was conducted at the Faculty of Agronomy of the Autonomous University of Sinaloa, in northwestern Mexico (24° 37’ N, 107° 26’ W; 22 m above sea level). The region has a warm semi-arid climate (BSh, according to the Köppen classification), with a mean monthly temperature of 24.6 °C, maximum and minimum temperatures of 43 °C and 0.6 °C, respectively, and an average annual precipitation of 705 mm, concentrated between July and September. The soil is clayey, with a field capacity moisture content of 0.462 cm^3 cm^{-3}, a permanent wilting point of 0.348 cm^3 cm^{-3}, and a bulk density of 1.12 g cm^{-3}.

The study period lasted 89 days, counted from the time of transplanting (02/29/2024-05/27/2024); Persian cucumber cv. 'Camil' was used as the plant material. The experiment was established in four beds measuring 0.6 m × 7.5 m, spaced 1.5 m apart, with 25 plants per bed (0.3 m between plants), for a total of 100 plants. Five treatments (Table 1) were evaluated with four replications, resulting in a total of 20 experimental units, each consisting of five plants.

Irrigation was carried out by drip irrigation and managed in real time, applying daily the consumed and estimated water depth (ET) calculated using the FAO Penman-Monteith method (Allen *et al.*, 1998), except during the water stress periods. To determine daily ET, data were obtained from a weather station installed the shade-net structure and equipped with sensors to measure air temperature, relative humidity, barometric pressure, net solar radiation, and soil heat flux. Soil moisture content was measured using a CS616 TDR sensor (Campbell Scientific®).

During the periods defined as water stress, irrigation was withheld until 80% of the total available soil water (TAW) accessible to the plant had been depleted (Equation 1). Two water stress periods were established: the first from 52 to 54 days after transplanting (DAT), and the second from 72 to 74 DAT.

$$HTA = \left(\theta_{cc} - \theta_{pmp}\right) Pr\, Pr\, P \tag{1}$$

Where: θ_{cc} it is the moisture content at field capacity (cm^3 cm^{-3}), θ_{pmp} is the content at permanent wilting point (cm^3 cm^{-3}), *Pr* is the soil depth considered and equal to 0.4 m, and *P* is the percentage of wetted soil and equal to 0.35.

The growth variables measured were plant height and stem diameter, while the production variables were fruit length, diameter, and weight, as well as final yield. A randomized complete block design with four replications was used. Data were analyzed using ANOVA, after verifying the assumptions of normality and homoscedasticity. Mean comparisons were performed using Tukey's test (α=0.05) with Minitab® 22.1 (2024) software.

RESULTS AND DISCUSSION

In the present study, the growth variables plant height and stem diameter showed no significant differences among the treatments evaluated (Table 2). Nevertheless, it was

Table 1. Treatments used in the experiment.

Number	Product	Dose (g L^{-1} of water)
T1	Control	No application
T2	Kaolin	30
T3	Kaolin	50
T4	Chitosan	3.5
T5	Chitosan	5

Table 2. Mean grouping of the evaluated variables.

Treatment	h (cm)	Dt (mm)	Lf (cm)	Df (mm)	Pf (g)	Yield (t ha^{-1})
T1	175.1 a*	8.2 a	14.3 a	46.0 ab	189.6 b	12.9 b
T2	180.4 a	8.5 a	14.8 a	46.5 ab	201.7 ab	17.9 ab
T3	178.4 a	8.4 a	15.0 a	48.1 a	216.8 a	16.1 b
T4	177.5 a	8.0 a	15.3 a	48.0 ab	220.0 a	25.2 a
T5	178.3 a	8.4 a	15.5 a	44.8 b	201.5 ab	14.7 b

h=plant height; Dt=stem diameter; Lf=fruit length; Df=fruit diameter; Pf=fruit weight; Yield=yield.
*Values followed by different letters within the same column indicate significant differences according to Tukey's test (0.05).

observed that the kaolin treatments (T2 and T3) produced the greatest plant height, with increases of 3.0 and 1.9%, respectively, relative to the control treatment. Likewise, in the chitosan treatments (T4 and T5), the relative difference compared with the control was 1.4 and 1.8%, respectively. This result suggests that, under the experimental conditions established, the foliar application of chitosan and kaolin did not significantly influence the vegetative growth of cucumber, which may be associated with the dose applied, the timing of application, or the absence of sufficiently severe stress conditions capable of restricting crop development. The absence of chitosan effects on plant height is consistent with the findings reported by Reyes *et al.* (2025), who likewise observed no significant differences in this variable in cucumber. However, those authors did record an increase in stem diameter following the application of chitosan nanoparticles. This discrepancy may be attributed to variations in concentration, the form in which chitosan was applied, and differences in the environmental and genetic conditions of the crop, all of which influence plant physiological responses to chitosan (Hidangmayum *et al.*, 2019).

With respect to kaolin application, there are no specific and recent studies in cucumber under water stress that allow for a direct comparison. However, the present results contrast with those obtained by Faghihi *et al.* (2025) in thyme (*Thymus vulgaris* L.), who reported significant increases in plant height and stem diameter under water stress conditions. Similarly, AbuEl-Leil *et al.* (2024) found that the foliar application of 300 ppm kaolin under water stress conditions in geranium significantly increased plant height (30.55%) compared with untreated plants subjected to the same irrigation level.

This discrepancy may be explained by interspecific differences and by the role of kaolin as an abiotic stress mitigator, since its effect becomes more evident in environments characterized by high temperatures or water deficit, where it reduces incident radiation and leaf temperature (Abdallah, 2019). Additionally, Faghihi *et al.* (2025) reported that increasing kaolin concentration from 4 to 8% reduced growth variables in thyme, suggesting a dose-dependent effect. Excessive particle coverage may limit the interception of photosynthetically active radiation and, consequently, reduce the photosynthetic rate, as has been reported in other crops (Cantore *et al.*, 2009). In this context, the absence of statistical differences in the present study may indicate that the concentrations used were insufficient to generate a detectable physiological response in the vegetative growth of cucumber.

Among the production variables evaluated (fruit length, fruit diameter, fruit weight, and yield), significant differences were observed among treatments, with the exception of fruit length (Table 2). With respect to yield, treatment T4 recorded the highest value, with a relative increase of 94.3% compared with treatment T1. Meanwhile, treatment T2 showed no statistically significant difference relative to either the best-performing treatment (T4) or the treatment with the lowest value (T1); however, the relative yield difference between T2 and T1 was 38.8%. Chitosan application enhanced cucumber yield, in agreement with the findings reported by Reyes *et al.* (2025). However, unlike what was reported by those authors, in the present study an increase in the chitosan dose did not translate into an additional improvement in yield. Similarly, Shehata *et al.* (2012) reported that foliar application of chitosan in cucumber achieved the highest yield at a dose of 4 mL L^{-1}.

The application of chitosan and kaolin improved cucumber yield under shade-net and water stress conditions by promoting fruit development and filling. The doses of 3.5 mL L^{-1} of chitosan and 30 mL L^{-1} of kaolin proved to be the most efficient, generating the greatest increases in yield without negatively affecting vegetative growth.

CONCLUSIONS

The application of chitosan and kaolin improved cucumber yield under shade-net and water stress conditions by promoting fruit development and filling. These results confirm the potential of both inputs to mitigate water stress in protected production systems.

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