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Enhancing Heat Stress Resilience of Tomato During Flowering Stage Using Biostimulants: Nano Chitosan and *Spirulina platensis* Extract

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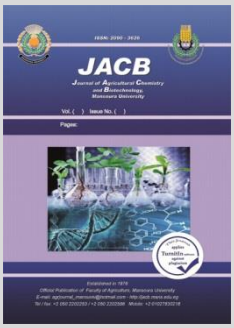

ABSTRACT

Weather and climate have a significant impact on agriculture. The agricultural sector and crop yield are affected especially by increasing temperature, leading to heat stress on plants. Heat stress is causing overall yield reduction, and unfavorable traits, to plant death. This research is aimed to evaluate the efficiency of applying nano chitosan (Ch. NPs) and *Spirulina Platensis* extract (Sp. extract) as biostimulants to eliminate heat stress impact in tomato plants during the flowering stage. The application of biostimulants to enhance plant response to heat stress is one of the most effective, economical, and environmental approaches. In a controlled growth room with a vertical farming system, we evaluated the efficacy of foliar application of the (Sp. extract) 15% and (Ch. NPs) 50 ppm in regular growth conditions as well as in mitigating long-term moderate heat stress for 10 days (LTMHS) during the tomato flowering growth stage. Both showed remarkable results in flowering growth. Also, these results are associated with the accumulation of total soluble sugars, Phenolics, and flavonoids in heat-stressed plants. Finally, these findings recommend the application of (Ch. NPs) and (Sp. extract) in stressed conditions to mitigate the negative effects and increase overall plant productivity.

***Key words*:** Heat stress; Biostimulants; Vertical farming; Tomato (*Solanum Lycopersicum*).

INTRODUCTION

Over the last 250 years, a huge increase in greenhouse gases particularly CO_2 and CH_4 has been recorded at 30% and 150%, respectively. Such elevation led to an increase in overall global temperature (Hassan *et al*., 2020). As a result of that heat stress developed and caused significant damage to many edible crops. Heat stress is considered one of the main abiotic stresses and causes several unfavorable traits, affects seed germination, and decreases plant metabolism, especially during critical stages such as flowering. Several studies reported that abiotic stresses such as drought and heat lead to physiological disorders, and overall yield loss reach 50% ((Lamaoui *et al*., 2018). A recent IPCC (Intergovernmental Panel on Climate Change) report in 2021 mentioned that the last four decades have been successively warmer than any decade that preceded it since 1850. The global surface temperature was 1.09 °C [0.95 to 1.20] higher in 2011–2020 than in 1850–1900, with larger increases over land. (WGI IPCC, 2021).

(Zhao *et al*., 2017) estimated that each 1°C elevation, could decrease the total yield of important commodities by 4.1% - 6.4%. which has a negative impact on the economic and environmental levels.

Biostimulants are natural or synthetic substances that can be applied to seeds, plants, and soil to cause changes in vital and structural processes in order to influence plant growth through improved tolerance to abiotic stresses and increase seed and/or grain yield and quality. Application of biostimulants to plants intending to enhance abiotic stress tolerance and/or crop quality traits that will be a great organic and sustainable solution to increase plant resilience against heat stress.

Tomato (*Solanum Lycopersicum L*.) belongs to the family *Solanaceae* and is one of the most sensitive crops to heat stress. In addition, a strategic crop not only in Egypt. But also, globally. According to (*FAOSTAT*, 2020), the production of tomatoes is growing each year globally. The total world production of tomatoes is 187 M tonnes in 2020. Egypt comes in fifth place among the top ten producers of tomatoes during the period from 2000 to 2020. The production of tomatoes was 170k tonnes and the total harvested areas in Egypt was seven million tonnes in 2020 (see Figure 1). However, tomatoes' production and yield have declined during the previous 10 years (FAOSTAT, 2020).

Using a biostimulant that could lessen the heat stress impacts' is an evolving trend nowadays. These biostimulants are organic materials such as humic acids, Osmo protectants, amino acids, and algal extracts. (Carmody *et al*., 2020) made exogenous application of two different *Ascophyllum nodosum* extract which improved the resilience of tomatoes by 80% over untreated plants for long-term moderate heat stress. Biostimulants treatment of cucumber seeds helped mitigate the impact of heatwaves by almost 6% in germination (Campobenedetto *et al*., 2020). The application of cyanobacteria has a proven role in plant improvement (Godlewska *et al*., 2019).

Therefore, the current study was designed to investigate the efficacy of the exogenous application of biostimulants (Sp. Extract) and (Ch. NPs) on long-term moderate heat stress in tomato plants.

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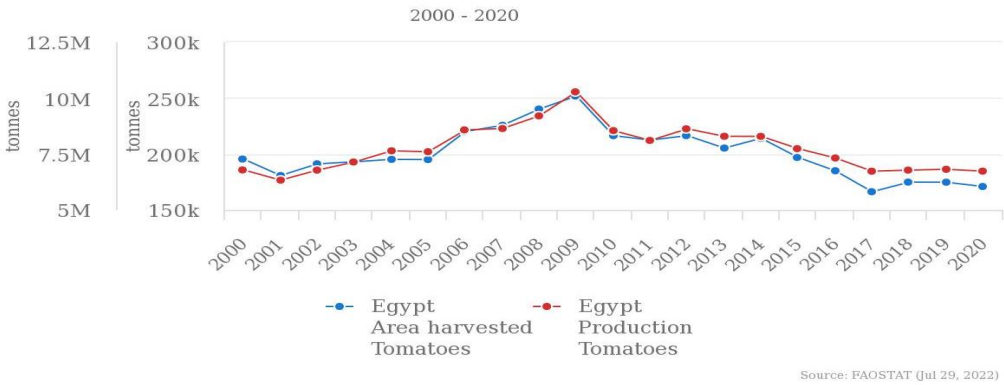


Figure 1. Production/ yield quantities of tomatoes in Egypt, 2000- 2020. (*FAOSTAT*, 2020)

MATERIALS AND METHODS

In this research, pots were placed with normal soil in vertical farming instead of using the hydroponic system in a controlled growth room.

1- Plant Material and Growth Conditions:

Tomato seeds (cerein f1 cultivar) were purchased from a local seeds store and sown in plug trays filled with a growth medium composed of peat moss. On day eighteen, seedlings were transferred to 4L pots containing a growth medium composed of compost: clay: and sand (1:1:1) respectively with the addition of 5 g slow-release NPK fertilizer containing NH_2/P2O5/K2O (7/7/7, w/w/w)]. 75 pots were raised in a growth room at a temperature of 25°C ± 2°C with 16 h of daylight and 8 h of night and 60 ± 5% relative humidity (RH) under a light intensity of 320 µmol m^{-2} s^{-1} in a complete randomized block design. Plants were regularly irrigated and fertilized with needed minerals in consideration of Table 1. which was obtained from (Schwarz *et al*., 2014).

Table 1. Recommended levels of nutrients for tomato production.

Nutrient/ element	g/ kg soil.
N	1.5
P	0.2
K	1.5
Ca	0.7
Mg	0.2
S	0.4
Fe	0.007
Mn	0.006
Zn	0.008
Cu	0.008
B	0.01
Mo	0.001

2- Bulk chitosan manufacturing:

Shrimp shells were first washed with water to remove sand and other impurities. Furthermore, these shells are demineralized by hydrochloric acid to remove minerals from shells. Thirdly, the obtained shells are deproteinized by a powerful base such as potassium hydroxide to remove proteins attached to chitin nanofibers. Fourthly, these chitin flaxes will be deacetylated using (the Broussignac process) to remove the acetyl group and produce chitosan. (Khaled, 2021)

3- Nano chitosan manufacturing:

Chitosan powder was dissolved in 1% (w/v) acetic acid solution until the solution was transparent. After that, Sodium tripolyphosphate (TPP) was dissolved in deionized water at a concentration of 0.5 % (w/v). Then TPP solution was poured dropwise into the chitosan solution under magnetic stirring using a stirring bar. The formation of Ch. NPs started spontaneously *via* the initiation of the ionic gelatin mechanism induced by TPP that appeared in (Figure 2. a) The synthesized Ch. NPs were characterized by FTIR, dynamic light scattering (DLS), zeta potential, and transmission electron microscope (TEM).

a. Spirulina extract production:

Fermentation was performed in a 500 mL conical flask with 250 mL of standard Zarrouk culture medium (Paris *et al*., 1966.), and 10% inoculum with controlled light and bubbled with air. The biomass was harvested by centrifugation on day twenty of cultivation. Moreover, Sp. extract (Figure 2. b) was made by vigorously stirring to disrupt the spirulina cells and release all the metabolites in the solution that was diluted and used in this experiment.

b. Treatments application and stress conditions:

In the time of flowering with a significant presence of flowers, 90 days, sixty pots are divided into six groups that were placed in a total randomized block design described in Figure 3.

Figure 2. a

Figure 2. b

Figure 2. (a) White suspension indicates nanoparticle formation, (b) Sp. extract.

Figure 3. Total randomized block design in the climate growth room.

Before the treatments' application, a dilution of Sp. extract to 15% was prepared for plant foliar application. In addition, Ch. NPs were prepared at 50 ppm to be ready for foliar application. Three days before separating pots, foliar application of Ch. NPs, Sp. extract and distilled water for control groups had been made.

Furthermore, (Control, HS), (Sp. extract, HS), and (Ch. NPs, HS) were exposed to (LTMHS) for 10 days in a growth chamber (33°C ± 2°C with 16 h of daylight and 8 h of night and 60 ± 5% relative humidity (RH) under a light intensity of 320 µmol m−2 s−1 in a complete randomized block design. 2 days before the stress application and during the stress on day five, another foliar application had been made. After the heat stress period, many measurements were investigated, leaf samples were collected 2 h after the end of the light period to avoid any influence of plant day-night cycle on soluble sugar profiles, snap-frozen in liquid nitrogen, ground, and kept in −80°C until further analysis.

c. Monitoring plant height, the total number of branches, flowers, tomatoes, and photosynthetic performance:

Plant height and the total number of branches, flowers, and tomatoes were monitored on day zero of stress starting, after one week of stress, and after ending stress by two days to avoid plants' immediate shock.

Concerning photosynthetic activity, chlorophyll content, as an indicator of photosynthetic activity and nitrogen status, was measured during the experiment using a portable SPAD-502 (Konica Minolta) device, on the last three fully expanded leaves per plant.

d. Flavonoids, Phenolic Compounds, and Total Soluble Sugar Content in Plant Leaves:

Total flavonoids:

The total flavonoid content of tomato extract was measured using a colorimetric aluminum chloride test (Zhishen *et al*., 1999)(Leamsomron *et al*., 2009). 150 ml of 5% sodium nitrate and 0.5 ml of the extract were combined, and the mixture was let to stand for 6 minutes. After adding 150 l of 10% aluminum chloride solution, the mixture was thoroughly mixed with 200 l of 1 M sodium hydroxide solution before being diluted to 5 ml with methanol. The absorbance was measured spectrophotometrically at 510 nm against a blank after 15 minutes of incubation. The total flavonoid content was calculated in milligrams of quercetin equivalents (QE) per gram of extract (mg QE/g). The number of total flavonoids was calculated using the quercetin standard curve.

Total phenolic compounds:

At room temperature, 25 ml of 80% ethanol was stirred with 15 g of finely ground, air-dried tomato plant leaves until the extraction solvent was colorless. The Folin-Ciocalteu reagent and gallic acid as a standard was used to quantify the total phenolic contents (Kujala *et al*., 2000). Concisely, 2.5 mL of Folin-Ciocalteu reagent (diluted 1:1 with ethanol) and 2 mL of Na_2CO_3 (7.5%) were added to 0.5 mL of filtered extract and thoroughly mixed. A Jenway 6405 UV-Vi spectrophotometer was used to measure the mixes' absorbance at 765 nm after 15 minutes of incubation at room temperature. Using a calibration curve of standard Gallic acid solutions, the amount of total phenol was determined and expressed as mg Gallic acid equivalents (GAE) per gram of extract (mg GAE/g dry weight of extract).

Total Soluble Sugars:

Total soluble sugars were determined using the anthrone technique described by (Umbreit, *et al*, 1964). 6 mL of anthrone solution (2g/l LH_2SO_4 95%) was added to a 3 mL sample and kept in a boiling water bath for 3 min. After cooling, the developed color was measured spectrophotometrically at 620 nm.

e. Soil analysis:

The concentration of each macro- and micro-mineral nutrient was determined separately for powdered dry soil samples that were collected from the sixty pots from the six groups.

f. Methods of analysis:

Data acquired were put through an analysis completely randomized design with the simple analysis of variance technique (Jones, 2016) using Statistical Package for the Social Sciences (SPSS Software - Egypt | IBM 2007.) Duncan's Multiple Range Test was used to separate homogenous populations. (Duncan, 1955) Differences among treatments were significant when $p \leq 0.05$.

RESULTS AND DISCUSSION

Results

1 Bulk chitosan characterization:

The quality of Ch. is dependent on many factors such as the degree of deacetylation. Using FT-IR JASCO 6300 Spectrometer the surface chemistry was characterized. The structure of chitosan flakes was confirmed by Fourier Transform Infrared analysis (FTIR), a spectrum in the range of 400-4000 cm^{-1} (See Figure 4.).

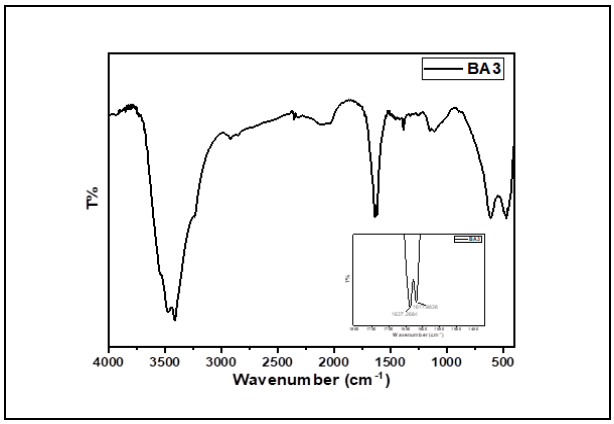


Figure 4. FTIR Spectrum of Chitosan.

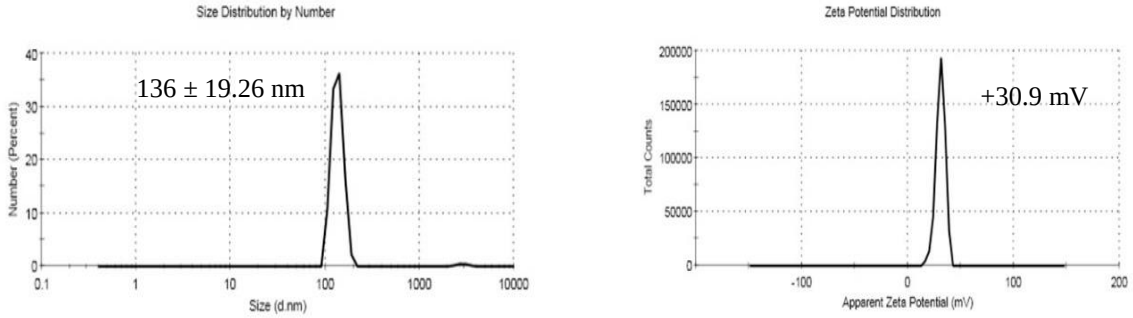
The chitosan flakes were observed to have an absorption band in the region of (3413 to 3471 cm^{-1}) which corresponded to the vibration of aliphatic O-H and NH stretching vibration (primary and secondary amino groups) of free amino groups (Ghannam *et al*., 2016), (El Knidri *et al*., 2018), and (Boudouaia *et al*., 2019). Another absorption band (2919 cm^{-1}) corresponded to the stretching asymmetric of -CH3 and -CH2. Also, an absorption band in the range from 2848 to 2919 cm^{-1} is due to the vibration of $NHCOCH_3$ and CH_2OH in the pyranose ring in chitosan. The bands of bending vibration of -NH2 and C=O in the NHCOCH3 group (amide I) (Ghannam *et al*., 2016), (El Knidri *et al*., 2018), and (Boudouaia *et al*., 2019), the important groups in the chitosan were seen at the band (1637 cm^{-1}) for chitosan. In addition, the stretching vibration for the C-N group linked to the OH group by bonding was indicated by the absorption band at (1620 cm^{-1}) (Ghannam *et al*., 2016), (El Knidri *et al*., 2018), and (Boudouaia *et al*., 2019). The -CH bending absorption band located at 1420 cm^{-1} is attributed to the vibration of the - CH_2 group Furthermore, the absorption bands at (1382, 1112, and 896 cm^{-1}) are attributed to the stretching vibration of C-O (1' alcohol), polysaccharide bond, and ring stretching of β-1,4 glycosidic bond, respectively (Ghannam *et al*., 2016), (El Knidri *et al*., 2018), and (Boudouaia *et al*., 2019). The deacetylation process to form chitosan was evaluated via FT-IR *via* Fatima *et al*. formula (Fatima, 2020). The calculated degree of acetylation was determined to be about 94.55%.

g. Nano chitosan characterization:

The synthesized Ch. nanoparticles were characterized by Fourier Transform Infrared analysis (FTIR), dynamic light scattering (DLS), zeta potential, and transmission electron microscope (TEM) observation.

DLS and zeta potential:

The chitosan exhibits good colloidal stability upon their DLS (see Figure 5-a) and zeta-potential data (Figure 5-b). In this regard, the hydrodynamic diameter (H D) was about 136 ± 19.26 nm, and the poly-dispersity index (PdI) was about 0.075, respectively. Furthermore, the Ch. NPs are positively charged based on their zeta-potential (η) data is +30.9 mV, respectively.



(**a**) (**b**)

Figure 5. (a) DLS data of Ch. Nanoparticles. (b) Zeta Potential data of Ch. NPs.

FTIR analysis:

FT-IR spectra for as-prepared Ch. NPs in Figure ٦. Ch. NPs are functionalized with numerous functional groups such as, $-CONH_2$, -OH, $-NH_2$, $-CH_2$, and -C=O, respectively. The characteristic peaks of Ch. NPs at 3411 and 1087 cm^{-1}, correspond to –OH and –C-O-C– stretching vibrations, in Ch. NPs (Behl *et al*., 2016). The – NH_2 bending vibration peak, was observed in chitosan at 1454 cm^{-1} in the case of chitosan-TPP nanoparticles and a distinct new peak appeared at 1637 cm^{-1} (Wu *et al*., 2005) (Ali Attia Shafie, 2013) (Behl *et al*., 2016). The peaks at 2927 and 2898 cm^{-1} are corresponding to the stretching vibration of C-H, and the peak at 1382 cm^{-1} belongs to the stretching vibration of the C-N bond (Wang *et al*., 2011). In addition, the stretching band of C–O in the chitosan spectrum was observed at 1049 cm^{-1} (Ali & Ahmed, 2018).

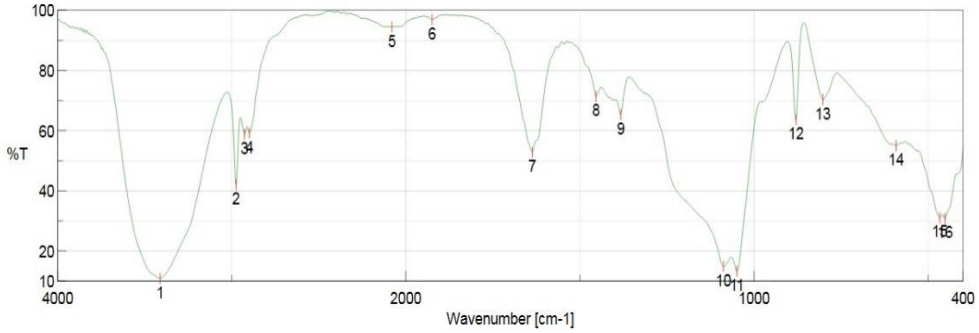


Figure 6. FTIR Spectrum of Ch. nanoparticles.

Transmission electron microscope (TEM) observation

The knowledge received on particle size determination and particle shape from (TEM). Figure 7 depicts a typical TEM micrograph of Ch. NPs. In addition, Images demonstrated the Ch. NPs physically aggregate and have a particle size of 100 nm.

h. Morphological data analysis:

A total number of sixty pots divided into six groups (10 pots per group) are statistically analyzed with the consideration of different treatments (Ch. NPs, Sp. extract, and control), different sampling times (before, within the stress, and after the stress), and the presence or absence of the heat stress.

Branches num.

According to Duncan's analysis of the mentioned three main factors, the lowest value is 6.90 which refers to the control group in heat stress. However, the highest value is ten which refers to the Ch. NPs group in heat stress also. The application of the Ch. NPs have a significant difference in the application of Sp. extract and control group, respectively. That is described in Figure 8. a.

Plant tall:

There is a significant difference among the three times of sampling, which means the heat stress significantly impacts the plant height.

Ch. NPs application has the highest value (34.60 cm) with a significant difference in comparison with Sp. Extract (31.20 cm) and the control group (28.50 cm) in the heat stress, respectively (Figure 8. b).

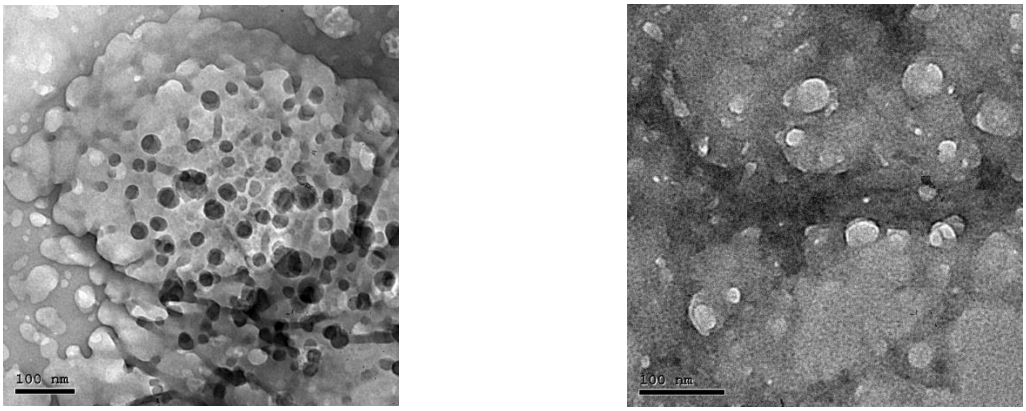


Figure 7. TEM images of Ch. NPs.

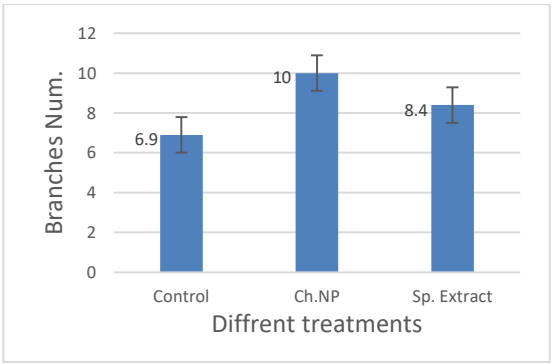


Figure 8. a

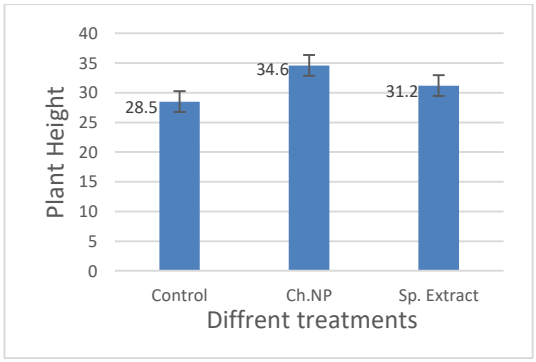


Figure 8. b

Figure 8. (a) Branches Num., (b) Plant Height.

Flower num.

Heat stress has a significant impact on the flowering stage and the flower numbers that are confirmed by the research here. There is no significant difference between the application of Sp. extract and Ch. NPs in enhancing the number of flowers. However, there is a tangible variation between Ch. NPs application and the control group that is affected by heat stress. (See Figure 9).

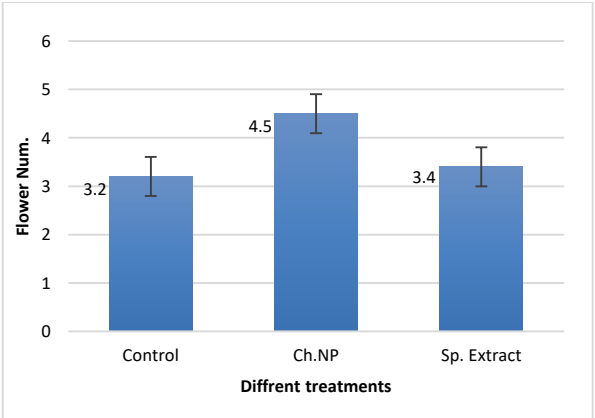


Figure 9. Flower num.

Chlorophyll content (measured one time after the stress period):

In Figure 10. a, there is no significant difference between the treatments and the control in increasing the chlorophyll content in the heat stress condition. However, Ch. NPs application significantly impacts the optimum condition in increasing chlorophyll content compared to the control in the same condition. In addition, there is no significant difference between the two treatments.

i. Flavonoids, Phenolic Compounds, and total soluble sugar content in plant leaves:

Flavonoids:

Foliar application of Ch. NPs significantly increase the flavonoids in plant leaves by 1.8695 mg/g in optimum conditions in comparison to Sp. extract and control groups. (See Figure 10. b).

The highest record of flavonoids in heat stress comes to the control group 1.5515 mg/g followed by Ch. NPs 1.0165 mg/g with the lowest level for Sp. extract 0.4048 mg/g.

Phenolic compounds:

In Figure 10. c, there is no significant difference between the Ch. NPs application and control in enhancing phenolics level in optimum condition. However, Sp. extract application increase phenolics level in plant tissues in heat stress conditions.

Total soluble sugar (TSS):

The highest record of TSS in optimum condition counts for Ch. NPs application with no significant difference with the control group. On the other hand, Sp. extract application increases TSS levels in plant tissues in heat stress conditions in comparison to the Ch. NPs and control group. See Figure 10. d.

j. Soil chemical analysis:

The tables below illustrate different mineral analyses of nitrogen, phosphorus, and potassium in the soil.

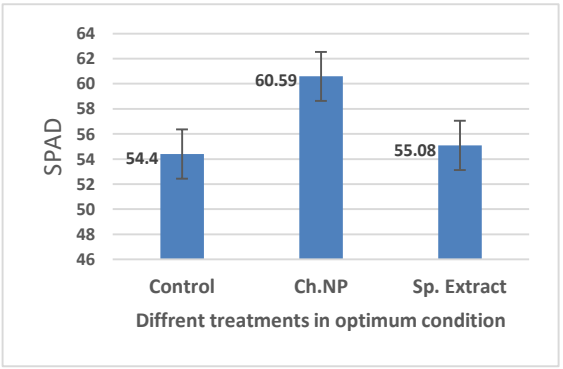


Figure 10. a

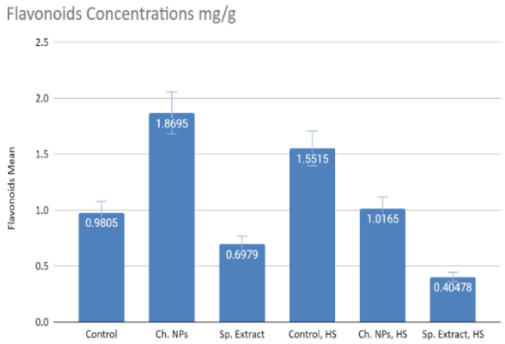


Figure 10. b

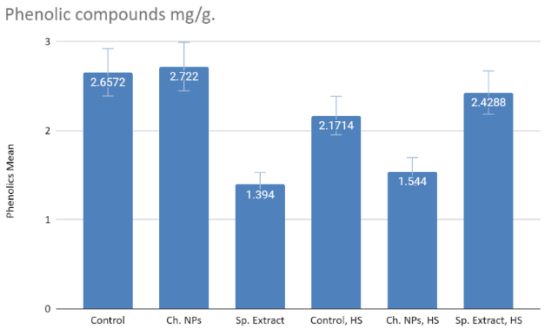


Figure 10. c

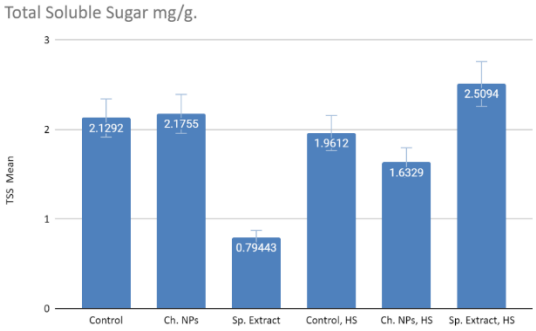


Figure 10. d

Figure 10. (a) Chlorophyll content, (b) Flavonoids Concentrations mg/g, (c) Phenolic compounds mg/g., (d) Total Soluble Sugar mg/g.

Nitrogen concentration in soil:

Soil nitrogen content in optimum conditions, the highest record in total nitrogen was 3500 mg/kg in the control group, where the available quantity was less than 10%. On the contrary, available nitrogen in the soil of Ch. NPs-treated plants were almost 40%. Moreover, Sp. extract enhance nitrogen availability to reach almost 28%. Figure 11. illustrates different nitrogen concentrations.

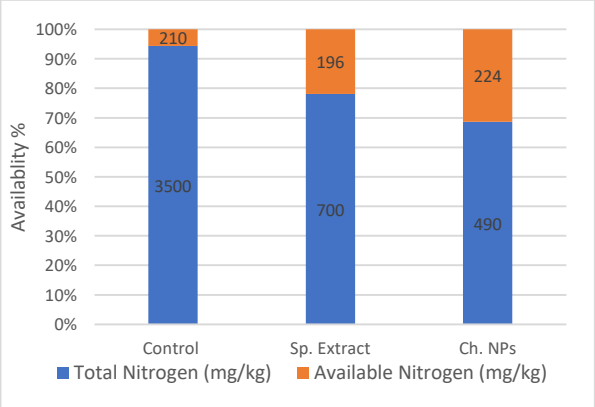


Figure 11. Nitrogen concentrations in soil in optimum condition.

The nitrogen concentrations are extremely diverse in heat stress. 5600, 1470, and 420 mg/kg for Sp. extract, Ch. NPs, and control group, respectively. The highest available percentage count for the control group in comparison to Ch. NPs, and Sp. extract. See Figure 12.

Phosphor concentration in soil:

Availability of phosphor in soil from highest, Sp. extract, control, and Ch. NPs respectively. See Figure 13.

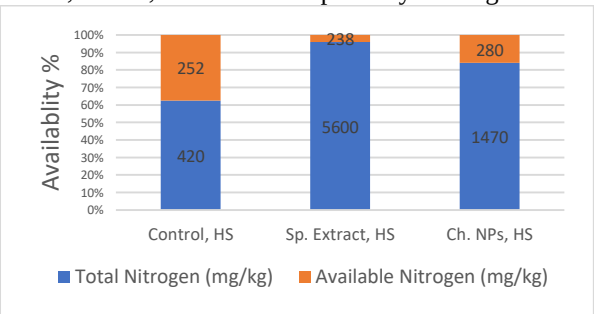


Figure 12. Nitrogen concentrations in soil in heat stress.

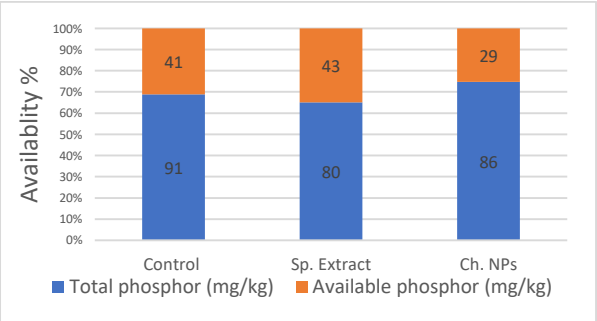


Figure 13. Phosphor concentrations in soil in optimum condition.

While the availability of phosphor in heat stress soil takes another manner. The control group is the dominant group for almost 40%, the Sp. The extract comes next 30%, and Ch. NPs at the last near 25%. See Figure 14.

Potassium concentration in soil:

The availability of Potassium is dominated by the control group count of almost 45%, and for both treatments is the same at 25%. See Figure 15.

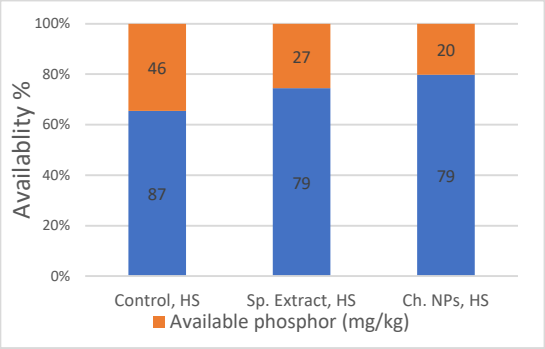


Figure 14. Phosphor concentrations in soil in heat stress.

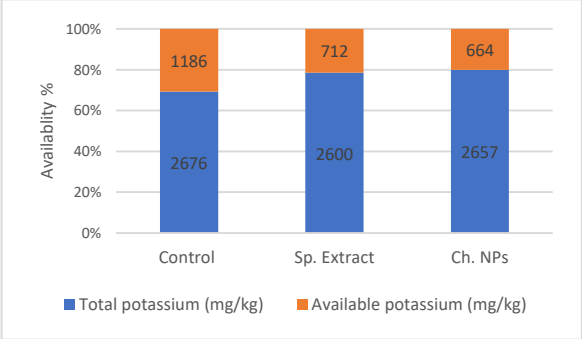


Figure 15. Potassium concentrations in soil in optimum condition.

No significant difference among results is the same for all diverse groups. See Figure 16.

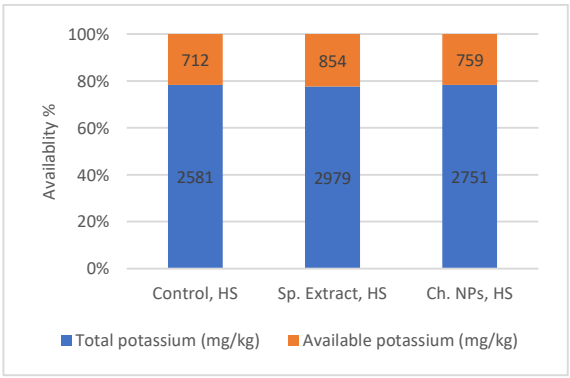


Figure 16. Potassium concentrations in soil in heat stress.

Discussion

This research indicates a significant flower loss due to elevated temperatures during the reproductive stage of tomato growth, reducing fruit set and production which is in agreement with results obtained by (Ahmad *et al*., 2010), and (Lokesha *et al*., 2019).

Elevated temperatures cause root heat stress and have an impact on nutritional quality due to a dysfunctional root-nutrient relationship. Additionally, restricts water delivery, nutrients, and the synthesis of hormones that affect sink-source relationships between roots and shoots, which in turn decreases the shoot system and eventual fruit output. (Wahid *et al*., 2007) (Zinn *et al*., 2010) (Giri *et al*., 2017). The use of biostimulants to reduce the consequences of abiotic stress has been described, and it has been found that they can strengthen plant defenses against unfavorable environmental factors. (Rady *et al*., 2019) (Alzahrani & Rady, 2019).

The foliar application of Ch. NPs at a concentration of 50 ppm significantly impact the morphological traits of tomato plants, especially under heat stress. Numerous uses of Ch. NPs in agriculture, including pesticides, herbicides, and insecticides, to produce larger yields of better-quality food items, have been thoroughly examined in the literature. (Kumaraswamy *et al*., 2018)

Furthermore, there are reports on the usage of bulk chitosan, notwithstanding the paucity of recent studies on the use of Ch. NPs to reduce heat stress. (Bandara *et al*., 2020) Consequently, Ch. NPs may function by causing antioxidant enzymes to be produced in plants and by controlling the amounts of Osmo protectants like proline. (Behboudi *et al*., 2018) Additionally, it was claimed that the chitosan-based rise in proline levels was related to an increase in proteinase enzyme activity. (Khordadi Varamin *et al*., 2018).

On the other hand, foliar application of the SP. extract significantly impacts metabolites such as phenolic compounds and TSS during stress conditions. This agrees with much research mentioned that plants can benefit from spirulina's abundance of macro- and micronutrients, including vitamins, amino acids, polypeptides, phytohormones (cytokines, auxins, and gibberellins), antioxidants, and substances with antibacterial and antifungal effects. (Nawrocka *et al*., 2017), and (Osman *et al*., 2016).

CONCLUSIONS

Climate change impacts agriculture specifically heat stress has irreversible damage, especially to heat-sensitive plants such as tomatoes, especially in critical stages such as fruit set, it will record the highest damage.

Foliar application of Ch. NPs enhance plant-acquired resilience against heat stress by improving morphological traits such as plant height and flower numbers. However, in this research application of Sp. extract does not significantly different in comparison to control groups specifically morphological traits. Sp. extract has a tangible impact on nutrient availability, which is critical to fruit set during heat stress. In addition, Sp. extract application increase phenolics level and TSS in plant tissues.

Finally, these findings recommend the application of Ch. NPs and Sp. extract in stressed conditions to mitigate the negative effects and increase overall plant productivity.

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تعزيز مقاومة الإجهاد الحراري للطماطم أثناء مرحلة الإزهار باستخدام المنشطات الحيوية :النانوشيتوزان ومستخلص السبيرولينا بلاتنسيس.

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الملخص

الطقس والمناخ لهما تأثير كبير على الزراعة. كما أن الزراعة تستخدم الموارد الطبيعية بكثافة مثل الأرض والمياه والأشياء الأخرى التي يؤثر عليها المناخ. يتأثر القطاع الزراعي وإنتاج المحاصيل بشكل خاص بزيادة درجة الحرارة ، مما يؤدي إلى الإجهاد الحراري على النباتات. يتسبب الإجهاد الحراري في تقليل المحصول بشكل عام ، والصفات التسويقية المرغوبة ، وفى النهاية موت النبات. كان الهدف من هذا البحث هو تقييم كفاءة تطبيق النانو كيتوزان (Ch. NPs) ومستخلص سبيرولينا بلاتنسيس (Sp. extract) كمحفزات حيوية للقضاء على تأثير الإجهاد الحراري في نباتات الطماطم خلال مرحلة التزهير. يعد تطبيق المنشطات الحيوية لتعزيز استجابة النبات للإجهاد الحراري أحد أكثر الحلول فعالية واقتصادية وبيئية. في غرفة النمو المتحكم فى الظروف بداخلها و بإستخدام نظام الزراعة العمودية ، قمنا بتقييم فعالية التطبيق الورقي من مستخلص سبيرولينا بلاتنسيس (سب. مستخلص) ١٥٪ و نانو شيتوزان (شو. نبس) ٥٠ جزء في المليون في ظروف النمو العادية وكذلك في التخفيف من الإجهاد الحراري على المدى الطويل لمدة ١٠ أيام (لتمس) خلال مرحلة نمو و تزهير الطماطم. أظهر كلاهما نتائج ملحوظة في نمو الإزهار. أيضا ، ترتبط هذه النتائج بتراكم السكريات الكلية القابلة للذوبان والفينولات والفلافونويد في النباتات المجهدة بالحرارة. وأخيرا ، توصي هذه النتائج بتطبيق نانو شيتوزان و مستخلص سبيرولينا بلاتنسيس في ظروف الإجهاد للتخفيف من الآثار السلبية وزيادة الإنتاجية الإجمالية للنباتات.

الكلمات الدالة: الإجهاد الحرارى، المحفزات الحيوية، الزراعة العمودية، نبات الطماطم.