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Plant based titanium dioxide nano particles effects on antioxidant enzymatic activities on wheat under water stress

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Abstract: A pot experiment was conducted in natural environmental conditions in the experimental locality of Government College Woman University, Faisalabad, to investigate the effect of TNPs along with drought conditions on wheat (Giza 129 and Giza 133). The physiological and morphological attributes are studied. The soil used for this analysis was artificially spiked at different drought levels (30 % FC and 60% FC) and different levels of Titanium based (TNPs) were supplied to plants (4 and 5mg TNPs) to minimize effect of drought. The results of the present study revealed that the titanium NPs have capabilities to deeply interact at tissue level and play an active role in increasing their physiology under drought stress. It was shown that plant growth and biomass, photosynthetic pigments, gas exchange parameters and stomatal conductance properties were varied significantly ($p < 0.05$) by drought stress. The root and shoot fresh weight as well as dry weight and root length were increased under higher dosages of TNPs. The physiological attributes like photosynthetic pigments Chl a and Chl b contents were maximum at high doses of TNPs under 60% FC. Stomatal conductance (SC), net photo synthesis were minimum at low doses of TNPs. The concentration of antioxidants enzymes were increased under 60% FC as compared to 5mg TNPs in Giza 129 and increased in Giza 133. Pearson correlation coefficient, representing varietal differentiation and correlation in the physiochemical and morphological attributes. It is concluded that TNPs are effective to counteract the effects of drought stress and also have ability to enhance growth and metabolic activities of wheat.

Keywords: 1; Wheat 2; keyword 3 (List three to ten pertinent keywords specific to the article yet reasonably common within the subject discipline.)

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1. Introduction

Wheat (Triticum aestivum L.) is the most valuable crop globally, contributing around 30% of the world's grain production, covering almost 218 million hectares with an average yield of 771 million tons, and meeting the needs of 21% of the world's population. Rather than other cereal crops, wheat is the third-largest crop in the world. It provides food for thousands of people and is a significant source of proteins, fibers and carbohydrates which are compulsory for human nutrition [1-3]. Due to its high nutritional content and variety of uses, wheat is regarded as the second most important staple food for almost 50% of the world's populations. Although it dominates Pakistan's agriculture, the country's main crop only contributes 1.6% of GDP and shares 8.9% of the sector's added value[4, 5]. Wheat is normally grown in rain-fed conditions, however when the stress of the drought grows, the yield loss may happen globally [6, 7].

Drought stress is a threatening environmental issue that affects the production of crops and has a long-lasting impact on the agricultural sector. Wheat growth and development are impacted by drought stress, increasing the threat to producing a sustainable crop [5, 8]. High temperature and low precipitations level results in drought stress which alters plant growth and developmental processes [6, 9] such as reduced germination, growth rate, plant pigments composition, yield production, disturb membrane integrity, osmotic adjustment and regulation and plant water movement [10]. Plant improve their resistance mechanisms, that enabled them to withstand drought stress, although these processes varied between plant species and are dependent on other abiotic factors like plant temperatures and intense light [11, 12].

Nanotechnology is emerging as new strategy in agriculture field. It improves agriculture sector from few decades. Nanoparticles enhance plant development under unfavorable environments by activating a number of physiological and biochemical pathways [13, 14]. In comparison to conventional compounds, their small size (1 and 100 nm), active mobility, reduced surface area, gradual release, and high translocation make them a suitable option for plants [9, 15]. They have unique characteristics that enabled plants resistant to various abiotic stress including drought, salinity and heavy metals [16, 17].

Additionally, they act similarly to antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), and peroxidase (POX), nano-materials have been used to protect plants from oxidative stress. They have ability to mitigate adverse effects of drought stress by lowering MDA, H_2O_2 levels to stabilize various physiological processes in plants [18, 19]. Moreover, nanotechnology is playing beneficial role in preparing nanopacticles based fertilizers for increasing nutrient efficiency and lowering environmental protection costs. The metal and metal oxides nanoparticles possess various unique features such as their surface, optical, thermal, and electrical properties which make them distinct to other chemical fertilizers [20, 21].

TiO_2, the ninth most abundant element in the universe, is a well-known nanoparticle that is essential for plant growth and development. TiO_2 nanoparticles have noticeable effects on the morphological, biochemical, and physiological characteristics of the crop. TiO_2 nanoparticles counteract detrimental effects of water stress in wheat and improve growth development and yield in wheat seedling [22]. They increase the relative water content, reduces the damage caused by reactive oxygen species by improving antioxidant activities. TiO_2 NPs controls enzymes including glutamate dehydrogenase (NDH), nitrate reductase (NiR), glutamine synthase (GS), activity of various physiological and metabolic processes such as nitrogen metabolism [23]. TiO_2 nano-particles increases activity of enzymatic antioxidants such as peroxidases (POD), superoxidases (SOD) and catalases (CAT)[5, 24].

2. Materials and Methods

This pot experiment was conducted in natural environmental conditions in Taif university to evaluate the effect of SNPs along with drought conditions on barley physiological as well as morphological growth. Giza 121 and Giza 123 were the two varieties used in the trial, which were procured from a well reputed seed store. The twin varieties were raised in pots with defined amount of uniformly sieved soil to access the two concentrations (4 and 5mg TNPs) of foliar application of silicon nanoparticles on barley to resist the drought conditions artificially induced. This pot experiment comprised of three factorial randomized complete block design with three replicates each. The drought condition (30% FC and 60% FC) was induced in the third week after proper germination of barley seedlings in the pots followed by thinning.

2.1. Procurement of T0NPs and treatments application

The Titinium-based nanoparticles were obtained from a well reputed organization namely Nano-Pishgaman and were pure in their originality as well as composition. After their characterization, 4 mg and 5 mg powdered forms were converted into liquid form as working solutions for aerial sprays on barley as per the decided treatments. Foliar application was done during the 7th leaf stage. The pots were placed in canopies after 20 DAS to carefully manage irrigation regimes and to impose drought stress. Drought stress was sustained at 30% FC and 60% FC. Sowing was done specifically under uniform conditions for all the respective treatments and were raised in controlled conditions.

2.2. Harvesting and evaluation of growth characteristics

Plants were harvested 45 days after germination. All plants were cleaned using tap water to avoid surface impurities and then separated into roots and shoot. Roots were rinsed with 0.1 M HCl to eliminate surface metal contaminants and again with distilled water. Three representative plant samples were taken to measure plant fresh weights. Root and shoot fresh weights were measured with help of digital scale immediately after harvesting as well as root and shoot length was also recorded. Three sample plants were oven-dehydrated at 70 °C for 72 hrs. Until completely dried and then dry weights were measured.

2.3. Estimation of photosynthetic parameters

[25] Prescribed a quantification method the chlorophyll content in barley leaves. 0.2 g of randomly picked leaves were mixed in 10 ml of 96% methanol for one minute, then filtered and centrifuged for 10 minutes at 2500 rpm. Supernatant was extracted and acquired to quantify chlorophyll concentration at wavelengths of 666 (chlorophyll *a*), 653 (chlorophyll *b*), and 470 nm (total chlorophyll) with help of spectrophotometer (Model SM1200; Randolph, NJ, USA).

2.4. Stomatal conductance, net photosynthesis and rate of transpiration analysis

Fully developed leaves were laid down in a chamber of portable infrared gas analyzer from all three plants per treatment to evaluate stomatal conductance (A.D.C., Hoddeson, UK). The measurements were taken six days after the establishment of salt stress [26]. The [27] method was used to calculate net photosynthesis rate as well as rate of transpiration.

2.5. Estimation of osmolytes and non-enzymatic antioxidant constituents

Total phenolic contents were determined by [28] protocol, and the calibration curves were prepared over a range of defined units for best linear fit. To flavonoids, leaf ethanol extracts of samples were made by 50 mg of leaves blended in 10 mL of 85% ethanol, then filtered and re-extracted in ethanol. An end volume of 20 mL was intacted. Using this reaction mixture, flavonoids [29] were quantified. For proline contents determination, 0.1 g plant sample was grinded in 3% 5 mL aqueous sulfosalicylic acid. The digested liquid was centrifuged at 10,000g for 15 min. 1 mL from this sample was mixed with and 1 mL acidic ninhydrin and 1 mL glacial acetic acid. The left mixture was boiled, cooled and then vortexed. Absorbance was noted at 520 nm with help of spectrophotometer [30].

For the purpose of determining the EL, tubes containing distilled water were filled with 2-3 completely expanded leaves from representative plants, one from each replicate and left at room temperature and in the dark. Using a conduct meter, the solutions' electrical conductivity (EC 1) was assessed after 24 hours of incubation. The samples' ultimate electrical conductivity was measured after they had been boiled for 30 minutes to remove all of the electrolytes (EC 2). Below mentioned formula was used to estimate the EL [31].

$$\mathbf{EL\ (\%) = (EC\ 1/EC\ 2).100}$$

2.6. TSS and TSP evaluation

In accordance with the [3] method, 0.1 g of leaf portion was weighed and mixed in 5 mL of phosphate buffer having a pH of 7.8. By combining 0.2 g of Brilliant Blue Coomassie G250 with 10 mL of ethanol, 17 mL of 85% H_3PO_4 and 3 mL of distilled water in a beaker, Bradford reagent was formed. The liquid was filtered and diluted to 200 mL, which revealed a brown color. Following a 30-minute vortex period in test tubes containing 0.1 mL of sample and Bradford reagent of 4 mL and the absorbance was noted at 595 nm with spectrophotometer. For TSS, 1 g of fresh leaf was dissolved in distilled water (10 mL), boiled for an hour, and then filtered to determine the total soluble sugar content. Filtrate (1 mL) was diluted with DI water up to 5 mL. The filtrate was transferred to test tubes and mixed with 3 mL of freshly prepared anthrone reagent. This mixture was immediately vortexed and then heated at 90 °C for 20 minutes. After that at room temperature, it was cooled down. The absorbance was determined at 620 nm with pure water as a blank following (Yoshida et al. 1971) method.

2.7. Determination of oxidative stress indicators

Malondialdehyde (MDA) constituents were studied by crushing 0.1 g of fresh leaf samples in the mixture of 1% polyethene pyrrole and 25 mL phosphate buffer (50 mM) and then centrifuged at 10,000g for 15 min. Then, mixture was boiled at 100 °C for about 20 minutes and immediately refrigerated in an ice bath. The absorbance of supernatant liquid was noted with help of spectrophotometer at 450, 532 and 600 nm, following techniques by (Heath and Packer 1968).

MDA = 6.45 (A532 - A600) - 0.56 × A450)

H_2O_2 was estimated using a homogenous mixing of 3 mL sample extract and 1 mL of 0.1% titanium sulfate in 20% H_2SO_4 v/v. The solution was centrifuged at 6000g for about 10 minutes. Color intensity was recorded at 410 nm by using a spectrophotometer by [32].

2.8. Statistical analysis

Evaluation of data was proceeded using two-way analysis of variance (ANOVA). Mean comparison test was performed with least significant difference test ($p < 0.05$) [33]. The graphical representation of data was carried out by using Microsoft excel. To identify associations in different treatment variables, we deployed Pearson’s correlation analysis.

3. Results

3.1. Morphological attributes

The integrated treatments of TNPs imparted a significant improvement in sustaining the plant growth parameters against the stress levels positively as elaborated in table 3.1. Both shoot and root fresh as well as dry weights were influenced under the varietal comparison as well as TNPs supplementation under stress conditions. Shoot fresh weight flourished well in D_{60} FC with application of 5 mg TNPs in V_1 and was little declined in V_2. Similarly, RFW was higher in V_1 under the same D_{60} FC conditions and lowest was found in V_1 at D_{30} FC with application of 4mg TNPs. Meanwhile, shoot dry weight as well as root dry weight represented the same trend and significant increase was observed in V_1 under the 5mg TNPs provision in D_{60} FC conditions followed by the stress treatments D_{30} FC. Root length, reduced to elevated drought stress under 4mg TNPs in V_1, but there is significant reduction of RL as compared to V_1 at D_{30} FC represented in (Fig. 1).

Table 1 Influence of integrated amendments of SNPS along with stress levels following varietal comparison on various growth parameters of barley [T_1 = 4mg TNPs, T_2 = 5mg TNPs].

Variety	**Treatments**	**Shoot fresh weight (g)**	**Root fresh weight (g)**	**Shoot dry weight (g)**	**Root dry weight (g)**	**Root length (cm)**
V1	T_1D_{30}	1.6 ± 0.2	1.2 ± 0.2	1.32 ± 0.45	1.033 ± 0.2	1.2 ± 0.18
	T_1D_{60}	2.7 ± 1.59	2.1 ± 0.153	2.4 ± 0.62	1.83 ± 0.1	1.9 ± 0.2
	T_2D_{30}	2.1 ± 0.1	1.54 ± 0.16	1.9 ± 1.04	1.3 ± 0.16	1.54 ± 0.90
	T_2D_{60}	3.1 ± 0.99	2.7 ± 0.1	2.93 ± 0.83	2.6 ± 0.21	2.4 ± 0.94
V2	T_1D_{30}	1.572 ± 0.104	1.24 ± 0.16	1.27 ± 0.10	1.043± 0.17	0.92 ± 0.026
	T_1D_{60}	2.7 ± 0.1	1.97 ± 0.17	2.42 ± 0.058	1.63 ± 0.19	1.3 ± 0.12
	T_2D_{30}	2.066 ± 0.15	1.5 ± 0.1	1.72 ± 0.054	1.30 ± 0.8	1.8 ± 0.99
	T_2D_{60}	3.028 ± 0.12	2.6 ± 0.90	2.85 ± 0.06	2.3 ± 0.7	2.2 ± 0.94

Values are means ±SD based on triplicate independent determinations, and different letters means significant difference as evaluated by LSD pairwise comparison test.

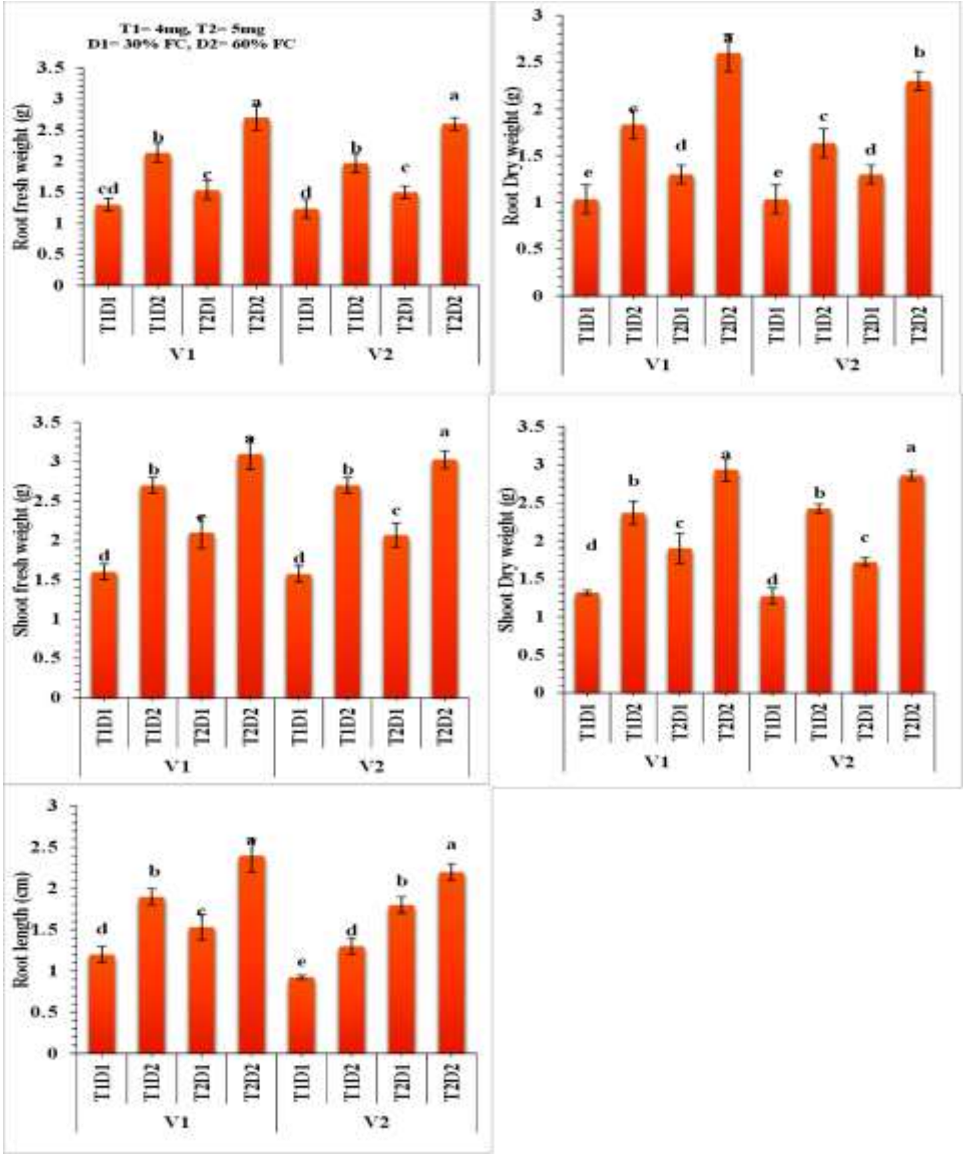

Figure 1 Photosynthetic parameters of barley as influenced by treatments of TNPs and drought.

3.2. Photosynthetic parameters

The chlorophyll contents also indicated a comparable influence of TNPs application under drought conditions as presented in table 3.2. The maximum chl *a.* and chl *b.* was recorded in V_1 under 5mg TNPs application at 60 FC and same combination in V_2 which represents the efficacy of planned treatments. The minimum chlorophyll contents were observed in $V_1T_1D_1$ and $V_2T_1D_1$. Similarly, the total chlorophyll contents (Tchl.) were also substantially increased in the $V_1T_1D_2$ at 60 FC treatment. But there are irregular variations among both varieties of wheat. In contrast to that, significant values of stomatal conductance were notable in the V_1 under 5mg TNPs application along with 60 FC drought conditions and minimal was observed in $V_2T_1D_2$. Moreover, other photosynthetic attributes such as, net photosynthesis and rate of respiration are more significant under higher applications of TNPs (5mg TNPs) at 60 FC. The minimum values of net photosynthesis and rate of respiration were recorded at $V_2T_2D_1$ and $V_2T_1D_1$ respectively. These variations are represented in (Fig.3.2B). These variations revealed the significance of NPs to counteract stress condition and also represent their positive impact on the accumulation of photosynthetic pigments.

Table 2 Influence of integrated amendments of TNPS along with stress levels following varietal comparison on photosynthetic parameters of barley [T_1 = 4mg TNPs, S_2 = 5mg TNPs].

Variety	Treatments	Chl. a (mg g^{-1} FW)	Chl. b (mg g^{-1} FW)	T. Chl. (mg g^{-1} FW)	Stomatal conductance	Net photosynthesis (µmol $m^{-2}s^{-1}$)	Rate transpira
V1	T_1D_{3o}	1.45 ± 0.13	0.77 ± 0.13	2.23 ± 2.19	2.27 ± 0.21	3.53 ± 0.199	4.4 ± 0.36
	T_1D_{60}	2.52 ± 0.08	1.9 ± 0.08	4.40 ± 1.41	2.75 ± 0.99	4.71 ± 0.07	6.67 ± 0.9
	T_2D_{3o}	1.18 ± 0.09	1.18 ± 0.005	2.36 ± 0.95	3.61 ± 0.9	4.55 ± 0.1	5.4 ± 0.15
	T_2D_{60}	1.85 ± 0.071	1.85 ± 0.007	3.71 ± 0.22	3.42 ± 0.94	8.71 ± 0.15	8.6 ± 0.99
V2	T_1D_{3o}	1.23 ± 1.14	0.059± 0.058	1.73 ± 0.15	2.92 ± 0.97	7.96 ± 0.17	3.54 ± 0.1
	T_1D_{60}	1.95 ± 0.04	0.028 ± 0.029	3.31 ± 0.07	1.64 ± 0.99	4.61 ± 0.19	4.64 ± 0.1
	T_2D_{3o}	1.73 ± 0.14	0.035± 0.036	2.7 ± 0.17	2.42 ± 0.19	2.72 ± 0.21	5.54 ± 0.2
	T_2D_{60}	1.57 ± 0.15	0.021± 0.021	2.45 ± 0.16	1.93 ± 0.15	6.56 ± 0.24	6.5 ± 0.36

Values are means ±SD based on triplicate independent determinations, and different letters means significant difference as evaluated LSD pairwise comparison test.

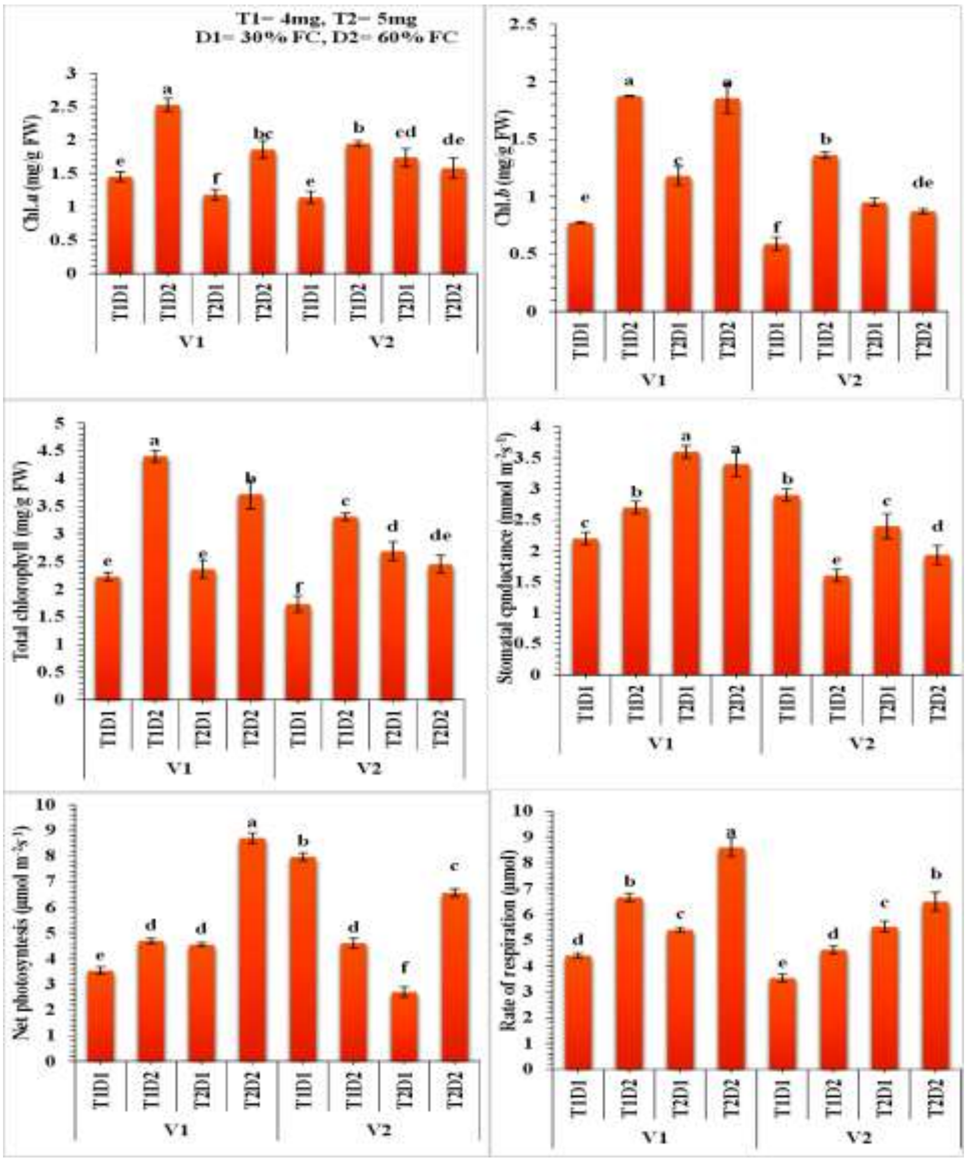

Figure 2 Photosynthetic parameters of barley as influenced by treatments of TNPs and drought.

3.3. Physio-chemical assessment

The physic-chemical attributes were mostly significant under all the conditions provided as represented in table 3.3. The physicho-chemical parameters like proline, total soluble proteins, total soluble sugars, Flavonoids, Hydrogen peroxide and MDA etc. were found to be highly significant in response to various drought treatments as well as TNPs under varietal comparisons. Proline contents differed significantly and increased in V_2 under all the treatments statistically lead by T_2D_1 and minimum were noted in the $V_1T_1D_2$ combination. The higher electrolyte leakage was observed in V_2 genotype at D_{30} FC as compared to V_1 at D_{30} FC with application of 4mg TNPs. Flavonoids contents were maximum in the V_2 and minimal in $V_1T_1D_2$ respectively. Total soluble proteins (TSP) as well as total soluble sugars (TSS) values were higher in V_1 and more or less statistically similar to each other in individual treatment of same genotype of each parameter. Phenolic contents were significantly enhanced in V_2 with the application of 4mg TNPs and also the average value was above normal in all the treatments, but in V_1 the maximum phenolic contents at D_{60} FC with 5mg applications. MDA along with H_2O_2 represented less variations under different treatments of TNPs, while, in V_2 was dominated under all treatments. V_1 assumed to be the most common and active variety in terms of physiochemical growth of wheat plant with 5mg treatment of TNPs along with 60 FC drought condition, showing significance of correlation in their interactive treatments and their applications. The varietal comparison and their mean differences are represented in (Fig. 3).

Table 3 Influence of integrated amendments of SNPS along with stress levels following varietal comparison on physio-chemical parameters of barley [S_1 = 4mg SNPs, S_2 = 5mg SNPs].

Variety	**Treatments**	**Proline (µg/g fwt)**	**Electrolyte leakage**	**Flavonoids**	**TSP (mg/g FW)**	**Phenolics (mg/g dwt)**	**TSS (µmol/g fwt)**	**MDA (µ mol g^{-1} FW)**	**H_2O_2 (µ mol/g fwt)**
V1	S_1D_o	0.19 ±0.008	28 ± 1.4	0.08 ± 0.062	0.70 ± 0.05	2.46 ± 0.64	0.09 ± 0.003	1.4 ± 0.9	2.2 ± 0.96
	S_1D_{60}	0.15 ± 0.009	21 ± 1.60	0.05 ± 0.003	0.77 ± 0.04	2.70 ± 0.65	0.084± 0.005	1.6 ± 0.5	2.67 ± 0.15
	S_2D_o	0.22 ± 0.015	23 ± 1.8	0.067 ± 0.04	0.83 ± 0.06	2.96 ± 0.95	0.067± 0.004	2 ± 0.49	1.8 ± 0.45
	S_2D_{60}	0.17 ± 0.005	13 ± 1.57	0.096 ± 0.05	0.95 ± 0.04	2.76 ± 0.58	0.056± 0.006	2.4 ± 0.93	3.23 ± 0.93
V2	S_1D_o	0.24 ± 0.012	31 ± 1.53	0.095 ± 0.04	1.46 ± 0.04	2.53 ± 0.40	0.12± 0.004	1.5 ± 0.98	2.3 ± 0.96
	S_1D_{60}	0.20 ± 0.09	22 ± 1.52	0.07± 0.005	1.32 ± 0.03	1.93 ± 0.70	0.095 ± 0.6	1.8 ± 0.96	1.9 ± 0.99
	S_2D_o	0.29 ± 0.01	27 ± 1.51	0.12± 0.002	1.14 ± 0.04	2.23 ± 0.76	0.081± 0.003	2.2 ± 0.97	2.6 ± 0.19
	S_2D_6	0.25	19 ±	0.081	0.95	1.90	0.071±	2.6	2.7

0	± 0.006	1.21	±0.00 25	± 0.05	± 0.81	0.002	± 0.9 6	7 ± 0.1 5

Values are means ±SD based on triplicate independent determinations, and different letters means significant difference as evaluated by LSD pairwise comparison test. (*= Significant, ** = highly significant, NS= non-significant)

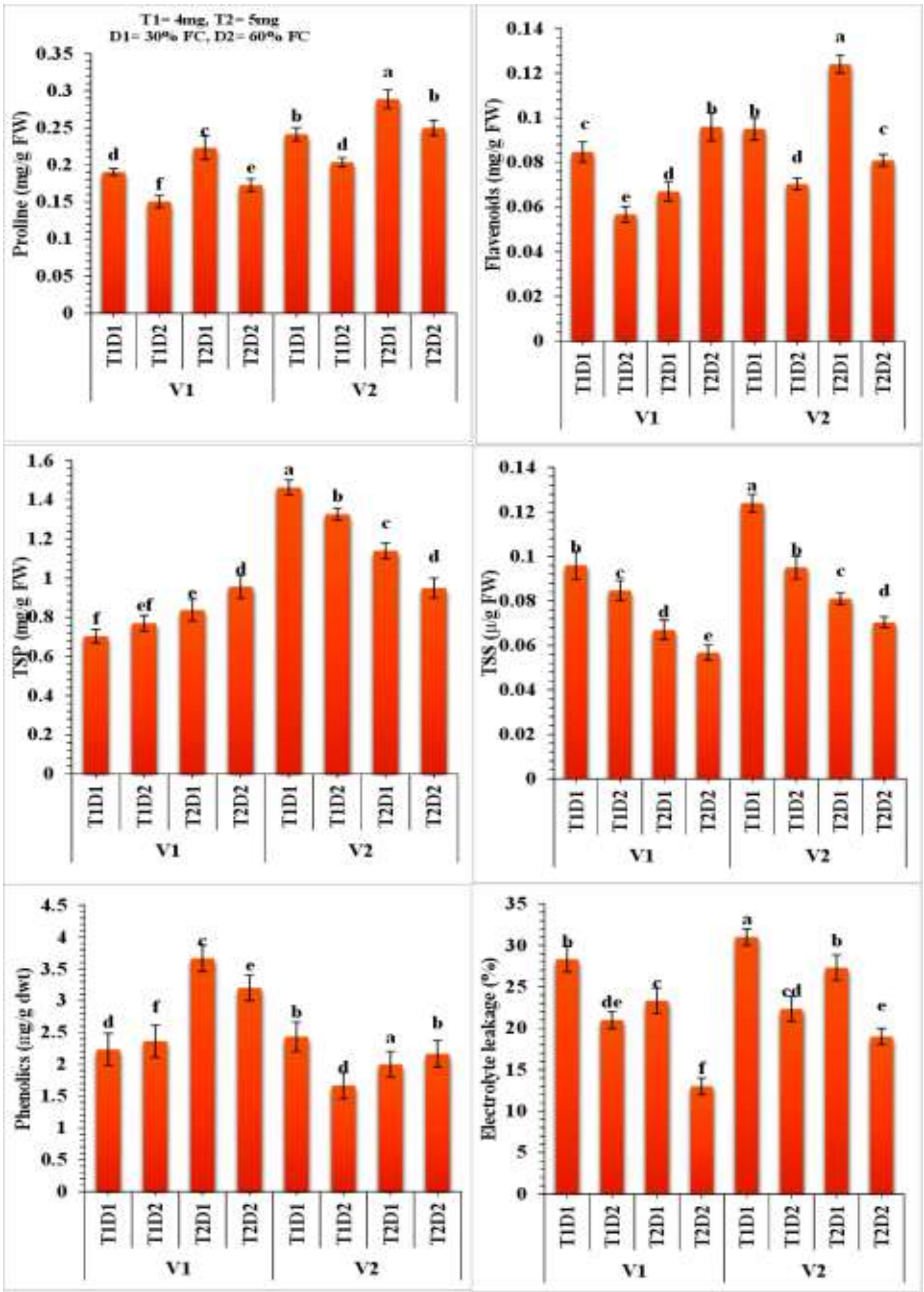

Figure 3. Photosynthetic parameters of barley as influenced by treatments of SNPs and drought.

3.4. Pearson correlation

Pearson correlation revealed that the physiochemical attributes were effectively correlated within the treatments devised. In Giza 121, most growth attributes (RFW, SFW and RL) were strongly positively correlated with physiological attributes (Chl*a* and Chl*b*) . In contrast, the activities of antioxidative enzymes (TSP, TSS, PRO) were strongly negative correlated with any growth and physiological attribute (STC). Electrolyte leakage showed strong correlation with net photosynthestic rate and rate of respiration (Figure 3.4a). Likewise, in Giza 123, all growth and physiological attributes were strongly positively correlated with physiological attributes (Chla, Chlb and RRE) except stomatal conductance and net photosynthetic rate didn't show correlation with growth attributes. The biochemical parameters (TSS, TSP, FLV, ECL and PRO) except MDA showed negative correlation with growth and physiological attributes (Figure 3.4b).

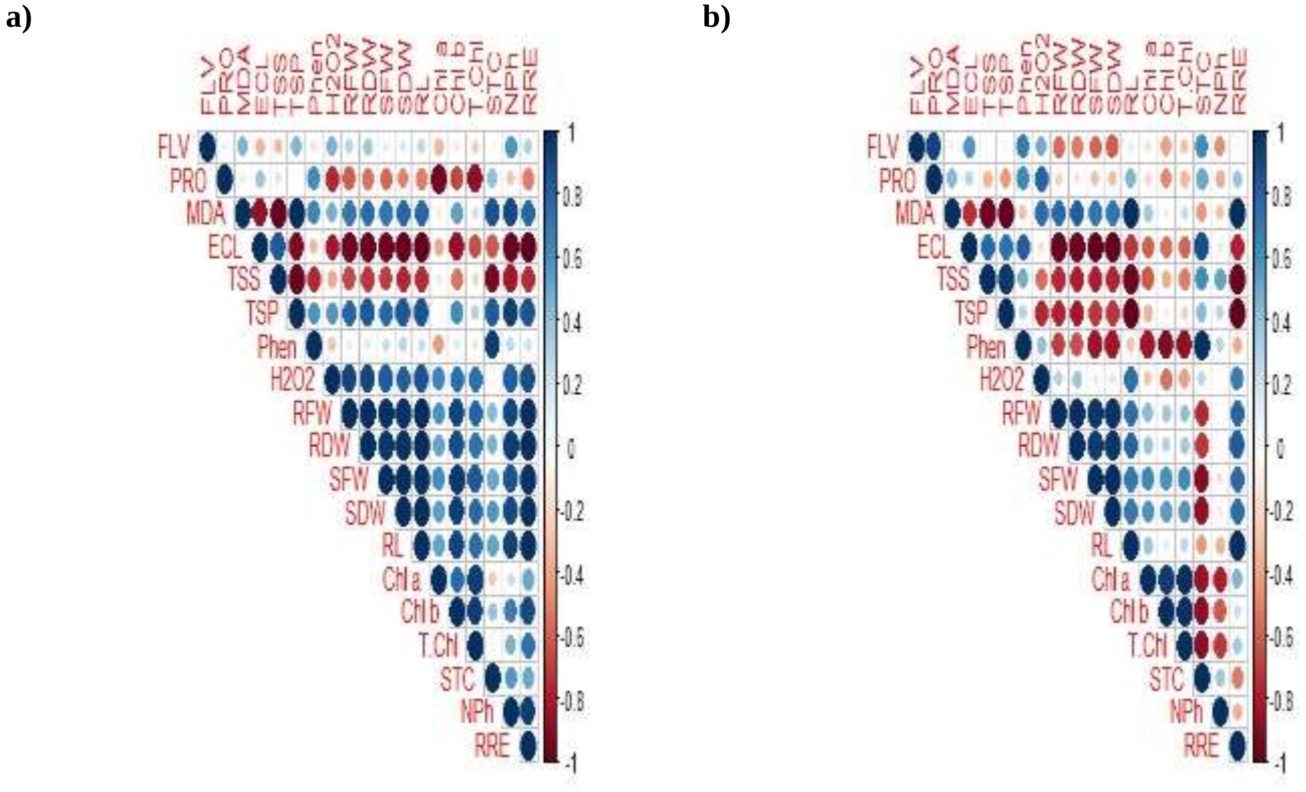

Figure 4 Pearson correlation of various physio-chemical attributes.

4. Discussion

This study was done to examine the effects of applying TNPs coupled with drought stress in two different genotypes of wheat. The main objective and key hypothesis in this study was to determine whether titanium oxide nanoparticles may assist different cereals to tolerate drought conditions help plants to perform their normal function. Thus, we started a study to see how wheat will response to the application of titanium oxide nanoparticles combined with drought treatments. It was determined in this study the nanoparticles help to improve antioxidant defense mechanisms in order to tolerate drought stress and enhance metabolic activities in wheat.

The growth attributes such as root and shoot fresh (RFW and SFW)as well as dry weights (RDW and SDW) varied significantly at 30% FC with 4mg applications of TNPs as compared to 60 FC, these findings are supported by [34], who revealed that the titanium dioxide NPs have the ability to interact extensively at the tissue level and actively contribute to enhancing their physiology. In addition to this they provide rigidity and strength to the root architecture of cereals.

The fresh weight as well as dry weight was significantly enhanced under higher dosages of TNPs (5mg TiO_2) and our findings are corresponding with those [35], who illustrated that a number of stress-resilient processes, TNPs may help cereal crops to grow physiologically in drought conditions, improving and boosting root and shoot properties. Because it starts accumulation of metabolites and reduces toxicity, titanium dioxide particle accumulation in wheat causes an increase in root/shoot biomass [36, 37].

Root length was increased by application of the TNPs which is also suggested by [37] who noted that plants with elongated roots may meet their nutritional and water needs as well as their own, and titanium nanoparticles can significantly reduce plants' losses from water absorption in drought conditions.

The photosynthetic pigments (Chl *a.* and Chl *b.*) increased under 5mg application of TNPs at 60% FC as the TNPs possess potential to elevate the photosynthetic activity under water deficient conditions as studied by [38]. [39] found that when TNPs are administered exogenously to any plant, both chlorophyll *a* and total chlorophyll increase because they improve photosynthetic activity. Moreover, the rate of transpiration and stomatal conductance was reduced when undergoes higher dosages of TNPs in our study which was affirmed by [40] who determined that when titanium particles are introduced exogenously, they are deposited in the leaves and limit stomatal conductance and transpiration rates. Same was studied by [5] that the water permeability is usually restricted by application of titinium nano particles.

The organic osmolytes proline contents were significantly varied in our study in both genotypes of wheat under different treatments which was coincide by the findings of [41]who illustrated that proline concentrations increase in current drought conditions mostly due to the activity of exogenously applied titanium dioxide nanoparticles. Foliar applications of titanium dioxide nanoparticles disrupt molecular structure of photosynthetic pigments due to stress conditions that enhance the flavonoids, Total soluble sugars and total soluble proteins concentrationsin wheat as demonstrated by[42] Hydrogen peroxide (H_2O_2) as well as MDA reduced to activate antioxidant enzymes (SOD and CAT) to minimize ROS production as identified by [43]. The Pearson correlation demonstrate the physiochemical parameters as positively correlated with growth parameters. Whereas, few biochemical attributes were negatively correlated with growth and physiological attributes. Foliar applications of titanium NPs enhanced plant growth and development by to capture light to perform enough photosynthesis and improving leaf water potential and osmoregulation to mitigate adverse effects of drought stress (Fig. 4) Thus titanium nanoparticles plays significant role to mitigate detrimental effects of drought stress The importance of titanium nanoparticles in reducing drought stress is thus confirmed, though future investigation and evaluation may need complicated interconnected studies.

Conclusion

After carefully reviewing the data analytics as well as comparison with the previous literatures, we can suggest 5 mg exogenous application of Titanium NPs in wheat being raised under drought conditions. Titanium nanoparticles have ability to follow up the drought effects and minimize them by increasing crop growth parameters as well as metabolic activities.

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References

1. Ahmadian, K., J. Jalilian, and A. Pirzad, *Nano-fertilizers improved drought tolerance in wheat under deficit irrigation.* Agricultural Water Management, 2021. **244**: p. 106544.
2. Daryanto, S., L. Wang, and P.-A. Jacinthe, *Global synthesis of drought effects on maize and wheat production.* PloS one, 2016. **11**(5): p. e0156362.

3. Bradford, M.M., *A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding.* Analytical biochemistry, 1976. **72**(1-2): p. 248-254.
4. Khadka, K., et al., *A physio-morphological trait-based approach for breeding drought tolerant wheat.* Frontiers in plant science, 2020. **11**: p. 715.
5. Mustafa, H., et al., *Biosynthesis and characterization of titanium dioxide nanoparticles and its effects along with calcium phosphate on physicochemical attributes of wheat under drought stress.* Ecotoxicology and Environmental Safety, 2021. **223**: p. 112519.
6. Adrees, M., et al., *Foliar exposure of zinc oxide nanoparticles improved the growth of wheat (Triticum aestivum L.) and decreased cadmium concentration in grains under simultaneous Cd and water deficient stress.* Ecotoxicology and Environmental Safety, 2021. **208**: p. 111627.
7. Rizwan, M., et al., *Alleviation of cadmium accumulation in maize (Zea mays L.) by foliar spray of zinc oxide nanoparticles and biochar to contaminated soil.* Environmental Pollution, 2019. **248**: p. 358-367.
8. Lian, J., et al., *Foliar spray of TiO2 nanoparticles prevails over root application in reducing Cd accumulation and mitigating Cd-induced phytotoxicity in maize (Zea mays L.).* Chemosphere, 2020. **239**: p. 124794.
9. Salajegheh, M., et al., *Effects of titanium and silicon nanoparticles on antioxidant enzymes activity and some biochemical properties of Cuminum cyminum L. under drought stress.* Banat's Journal of Biotechnology, 2020. **11**(21): p. 19-25.
10. Karvar, M., et al., *Titanium dioxide nanoparticles (TiO2-NPs) enhance drought tolerance and grain yield of sweet corn (Zea mays L.) under deficit irrigation regimes.* Acta Physiologiae Plantarum, 2022. **44**(2): p. 14.
11. Sanjari, S., et al., *Molecular, chemical, and physiological analyses of sorghum leaf wax under post-flowering drought stress.* Plant Physiology and Biochemistry, 2021. **159**: p. 383-391.
12. Golfam, R., et al., *A review of drought stress on wheat (Triticum aestivum L.) starch.* Farming and Management, 2021. **6**(1): p. 47-57.
13. Hussain, A., et al., *Seed priming with silicon nanoparticles improved the biomass and yield while reduced the oxidative stress and cadmium concentration in wheat grains.* Environmental Science and Pollution Research, 2019. **26**: p. 7579-7588.
14. Bashir, A., et al., *Combined use of zinc nanoparticles and co-composted biochar enhanced wheat growth and decreased Cd concentration in grains under Cd and drought stress: A field study.* Environmental Technology & Innovation, 2021. **23**: p. 101518.
15. Karamian, R., F. Ghasemlou, and H. Amiri, *Physiological evaluation of drought stress tolerance and recovery in Verbascum sinuatum plants treated with methyl jasmonate, salicylic acid and titanium dioxide nanoparticles.* Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 2020. **154**(3): p. 277-287.
16. Reddy, P.A.K., et al., *Enhanced hydrogen production activity over BiOXTiO2 under solar irradiation: Improved charge transfer through bismuth oxide clusters.* Journal of energy chemistry, 2017. **26**(3): p. 390-397.
17. Kirtane, A.R., et al., *Nanotechnology approaches for global infectious diseases.* Nature Nanotechnology, 2021. **16**(4): p. 369-384.
18. Rastogi, A., et al., *Impact of metal and metal oxide nanoparticles on plant: a critical review.* Frontiers in chemistry, 2017. **5**: p. 78.
19. Van Nguyen, D., et al., *Copper nanoparticle application enhances plant growth and grain yield in maize under drought stress conditions.* Journal of Plant Growth Regulation, 2021: p. 1-12.
20. Faraji, J. and A. Sepehri, *Exogenous nitric oxide improves the protective effects of TiO 2 nanoparticles on growth, antioxidant system, and photosynthetic performance of wheat seedlings under drought stress.* Journal of Soil Science and Plant Nutrition, 2020. **20**: p. 703-714.

21. Shallan, M.A., et al., *Biochemical and physiological effects of TiO2 and SiO2 nanoparticles on cotton plant under drought stress.* Research Journal of Pharmaceutical, Biological and Chemical Sciences, 2016. **7**(4): p. 1540-1551.
22. Jaberzadeh, A., et al., *Influence of bulk and nanoparticles titanium foliar application on some agronomic traits, seed gluten and starch contents of wheat subjected to water deficit stress.* Notulae botanicae horti agrobotanici cluj-napoca, 2013. **41**(1): p. 201-207.
23. Mahmoodzadeh, H., M. Nabavi, and H. Kashefi, *Effect of nanoscale titanium dioxide particles on the germination and growth of canola (Brassica napus).* 2013.
24. Shah, T., et al., *Seed priming with titanium dioxide nanoparticles enhances seed vigor, leaf water status, and antioxidant enzyme activities in maize (Zea mays L.) under salinity stress.* Journal of King Saud University-Science, 2021. **33**(1): p. 101207.
25. Dere, Ş., T. GÜNEŞ, and R. Sivaci, *Spectrophotometric determination of chlorophyll-A, B and totalcarotenoid contents of some algae species using different solvents.* Turkish Journal of Botany, 1998. **22**(1): p. 13-18.
26. Lalarukh, I., et al., *Exogenously applied ZnO nanoparticles induced salt tolerance in potentially high yielding modern wheat (Triticum aestivum L.) cultivars.* Environmental Technology & Innovation, 2022. **27**: p. 102799.
27. Reed, K.J., et al., *Cross sections for photodetachment of electrons from negative ions near threshold.* The Journal of Chemical Physics, 1976. **64**(4): p. 1368-1375.
28. Zieslin, N. *Effect of pH in the root environment on leakage from plant roots*. in *International Symposium on New Cultivation Systems in Greenhouse 361*. 1993.
29. Pękal, A. and K. Pyrzynska, *Evaluation of aluminium complexation reaction for flavonoid content assay.* Food Analytical Methods, 2014. **7**: p. 1776-1782.
30. Bates, D.G., *Nomads and Farmers: A Study of the Yo ̈ru ̈k of Southeastern Turkey*. Vol. 52. 1973: U OF M MUSEUM ANTHRO ARCHAEOLOGY.
31. Hniličková, H., et al., *Effect of salt stress on growth, electrolyte leakage, Na+ and K+ content in selected plant species.* Plant, Soil and Environment, 2019. **65**(2): p. 90-96.
32. Jana, S. and M.A. Choudhuri, *Glycolate metabolism of three submersed aquatic angiosperms during ageing.* Aquatic Botany, 1982. **12**: p. 345-354.
33. Steel, R.G.D. and J.H. Torrie, *Principles and procedures of statistics, a biometrical approach*. 1980: McGraw-Hill Kogakusha, Ltd.
34. Hojjat, S.S., *Effects of TiO 2 Nanoparticles on Germination and Growth Characteristics of Grass Pea (Lathyrus sativus L.) Seed under Drought Stress.* Nanotechnologies in Russia, 2020. **15**: p. 204-211.
35. Faraji, J. and A. Sepehri, *Ameliorative effects of TiO 2 nanoparticles and sodium nitroprusside on seed germination and seedling growth of wheat under PEG-stimulated drought stress.* Journal of Seed Science, 2019. **41**: p. 309-317.
36. Vittori Antisari, L., et al., *Uptake and translocation of metals and nutrients in tomato grown in soil polluted with metal oxide (CeO 2, Fe 3 O 4, SnO 2, TiO 2) or metallic (Ag, Co, Ni) engineered nanoparticles.* Environmental Science and Pollution Research, 2015. **22**: p. 1841-1853.
37. Satti, S.H., et al., *Titanium dioxide nanoparticles elicited agro-morphological and physicochemical modifications in wheat plants to control Bipolaris sorokiniana.* Plos one, 2021. **16**(2): p. e0246880.
38. Wang, Q.-L., et al., *Metabolic reprogramming in chloroplasts under heat stress in plants.* International journal of molecular sciences, 2018. **19**(3): p. 849.
39. Silveira, N.M., et al., *S-nitrosoglutathione spraying improves stomatal conductance, Rubisco activity and antioxidant defense in both leaves and roots of sugarcane plants under water deficit.* Physiologia Plantarum, 2017. **160**(4): p. 383-395.

40. Shafea, A.A., M.F. Dawood, and M.A. Zidan, *Wheat seedlings traits as affected by soaking at titanium dioxide nanoparticles.* Environment, Earth and Ecology, 2017. **1**(1).

41. Siddiqui, M.H., et al., *Sodium nitroprusside and indole acetic acid improve the tolerance of tomato plants to heat stress by protecting against DNA damage.* Journal of Plant Interactions, 2017. **12**(1): p. 177-186.

42. Gao, X., et al., *Distinct effects of soluble and bound exopolymeric substances on algal bioaccumulation and toxicity of anatase and rutile TiO 2 nanoparticles.* Environmental Science: Nano, 2018. **5**(3): p. 720-729.

43. Rai-Kalal, P., R.S. Tomar, and A. Jajoo, *H2O2 signaling regulates seed germination in ZnO nanoprimed wheat (Triticum aestivum L.) seeds for improving plant performance under drought stress.* Environmental and Experimental Botany, 2021. **189**: p. 104561.