Pak. J. Bot., 56(6): 2117-2121, 2024. DOI: http://dx.doi.org/10.30848/PJB2024-6(33)

EFFECTS OF *MESOPOROUS SILICA* (MCM) ON PHOTOSYNTHESIS, GRAIN YIELD AND QUALITY FORMATION OF WHEAT DURING FILLING STAGE UNDER DROUGHT CONDITIONS

BAOTING FANG[1], LINQING WANG[2], YANJING WANG[1,2], XIANGDONG LI[*], SIMENG DU[1], JUNQIN YUE[1], HAIYANG JIN[1], CHENG YANG[1], DEQI ZHANG[1], HANFANG WANG[1] AND YUNHUI SHAO[1]

[1]*Henan Province Engineering Research Center of Wheat Yield-Quality Simultaneous Improvement, Wheat Research Institute, Henan Academy of Agricultural Sciences, Zhengzhou 450002, China*
[2]*College of Life Science, Zhengzhou Normal University, Zhengzhou 450044, China*
**Corresponding author's email: tgzy123456@126.com*

Abstract

Drought is one of the major disasters affecting wheat production. Research on drought resistance induced by nanomaterials is of great significance not only for global food supply, but also for efficient utilization of resources. In this study, leaf spraying *Mesoporous silica* (MCM) at flowering stage was used to investigate the effects of MCM on photosynthesis and nitrogen utilization as well as the formation of final yield and quality during wheat filling. The results showed that MCM could effectively increase the photosynthetic pigment content and nitrogen utilization of wheat, improve grain yield and grain protein accumulation in wheat at the later stage of grain filling, and preliminarily proved that the effects of silicon on wheat drought resistance were affected by soil moisture content and dosage, which provided theoretical and technical support for the large-scale application of MCM in wheat production in the next stage.

Key words: Wheat, *Mesoporous silica*, Photosynthesis, Yield and quality.

Introduction

With the increase of the global population, the demand for food is increasing, and the waste of resources and environmental pollution caused by traditional inefficient cultivation techniques are increasingly concerned by people (Chen *et al*., 2022; Muhie, 2022). Nanotechnology has broad application space in different social fields. At present, in agricultural production, how to effectively use nanotechnology to improve crop resistance to biological and abiotic stresses is one of the key research contents(Haris *et al*., 2023).

Mesoporous silica refers to the silicon material with pore size between 2-50nm, which has high specific surface area and volume, thermal stability, thermal conductivity, good insulation and mechanical properties. It is a kind of drug carrier with great potential and has great application value in precision agriculture (Gupta *et al*., 2023).

Nano-silicon has good application effect in crop growth regulation and stress-resistant cultivation. Khoroshilov *et al*., showed that SiO_2 NPs (NanoKremniy LLC, Russia) had positive effects on photosynthetic potential, photosynthetic net productivity, chlorophyll, carotenoid and carbohydrate synthesis of spring wheat and meanwhile the leaf life extension(Khoroshilov *et al*., 2021). Studies by Siddiqui *et al*., showed that 8 g/L SiO_2 NPs could improve tomato seed vitality index and promote the increase of fresh and dry weight of seedlings. Compared with ordinary large particle silica, SiO_2 NPs has the characteristics of small size, large surface area and high reactivity, which can be used as an effective regulation for plant growth maintenance and improvement of crop quality and quality. However, under high salt conditions, the osmotic potential of plants is increased, Na^+ ion accumulation, and growth is inhibited. However, SiO_2 NPs can reduce ion accumulation by hindering Na^+ absorption, thus restoring plant growth and development(Siddiqui *et al*., 2014). Elsheery *et al*., showed that, under salt stress, the suitable concentration of SiO_2 NPs which was sprayed on the leaves can promote the physiological growth, nutrient absorption and carbon assimilation of mango, and the content of proline is higher, while the activity of antioxidant enzyme is positively correlated with the medium and low concentration of SiO_2 NPs. On the contrary, excessive concentration has inhibitory effect(Elsheery *et al*., 2020). Ashkavand's study shows that the adverse effects caused by drought stress can be reduced by SiO_2 NPs treatment. Meanwhile, it can also improve the photosynthetic efficiency and stomatal conductance of hawthorn (Ashkavand *et al*., 2015). In addition, Tripathi *et al.,* have shown that SiO_2 NPs can alleviate UV-B stress in wheat more effectively than conventional silicon by triggering an antioxidant defense system (Tripathi *et al*., 2017). Through the above analysis, it can be seen that exogenous mesoporous silica can affect plant photosynthesis, membrane lipid oxidation resistance and osmotic regulation, so as to improve plant stress resistance.

Although a lot of research has been done on the application of silicon in agricultural production, the application of nano-silicon, especially mesoporous silicon dioxide in wheat cultivation has not been reported on a large scale. Furthermore, the effects of mesoporous silica on carbon and nitrogen metabolism balance and grain sugar and protein accumulation in wheat have not been reported. Therefore, combined with the above research status, this study preliminatively explored the effects of foliar spraying of mesopore silica on wheat yield and quality formation through the water control method of pool planting.

Material and Methods

Test materials and setup: The study was conducted at the Stress Research Center of Henan Province, Modern Agricultural Research Base (E 113.7°, N 35.0°), Henan Academy of Agricultural Sciences from October 2021 to June 2022.The semi-winter wheat variety “Zheng Mai 1860” was used as the test variety, which was provided by Wheat Research Institute of Henan Academy of

Agricultural Sciences. The wheat planting management refers to the wheat high-yield field standard in northern China, and the compound fertilizer and organic fertilizer are applied at the bottom in one time before sowing. In the experiment, after the jointing period of wheat, the intelligent canopy was used to block the precipitation, and the water supply of each pool (1.44 ㎡) was artificially controlled at the flowering period of wheat. The handheld soil moisture tester was used to monitor the soil moisture content, so as to maintain the difference between the drought and normal soil water content.

MCM was sprayed on the leaf surface of wheat at the flowering stage (concentration: 1g/L; MCM was difficult to dissolve in water; after hot melting, it was needed to form a suspended turbidified mixture with water, and then sprayed after cooling to room temperature). MCM was provided by Sigma Company (pore volume: 2.31 cm^3/g, spec. surface area 562 m^2/g). Spray 250ml solution evenly into each pool, and cover leaves of different layers with a layer of water film. Water (CK) was used as control treatment, and each treatment was repeated 4 times. The indexes were sampled at early stage (ES), middle stage (MS) and late stage (LS) of wheat filling, and the yield components were determined after maturity.

Test methods: Leaf photosynthesis was measured by a photosynthetic apparatus (LI6400) (Xie *et al*., 2009). Nitrogen content in leaves was determined by nitrogen analyzer (N110) (Efretuei *et al*., 2016). Chlorophyll content was determined by SPAD (chlorophyll fluorescence analyzer) (Debaeke *et al*., 2006). As the wheat mature using artificial harvest and measuring yield. The research test grain nutrient analysis using crop grain nutrient analyzer.

Statistical analysis

Excel and SAS were used for data statistics and analysis, and the difference was significant (p<0.05).

Results

Changes of photosynthesis in flag leaves of wheat at different periods during filling period: As shown in (Fig. 1), under different water treatment conditions, net photosynthetic rate (Pn) and stomatal conductance (Gs) of MCM treatments had greater variation than that under CK treatment.

In the three grouting periods (ES, MS and LS), the Pn and Gs of MCM treatment were all lower than CK, but the PN and GS of normal irrigation treatment were higher than those of drought treatment, and the decrease of CK treatment was greater than MCM treatment in MS and LS period. The intercellular carbon dioxide concentration (Ci) in different treatments decreased first and then increased, while WUE gradually decreased, and there was no significant difference among different treatments. Based on the above analysis, the MCM of 1g/L can decrease Pn value and increase Gs in the later grout period, but has no significant effect on Ci and WUE.

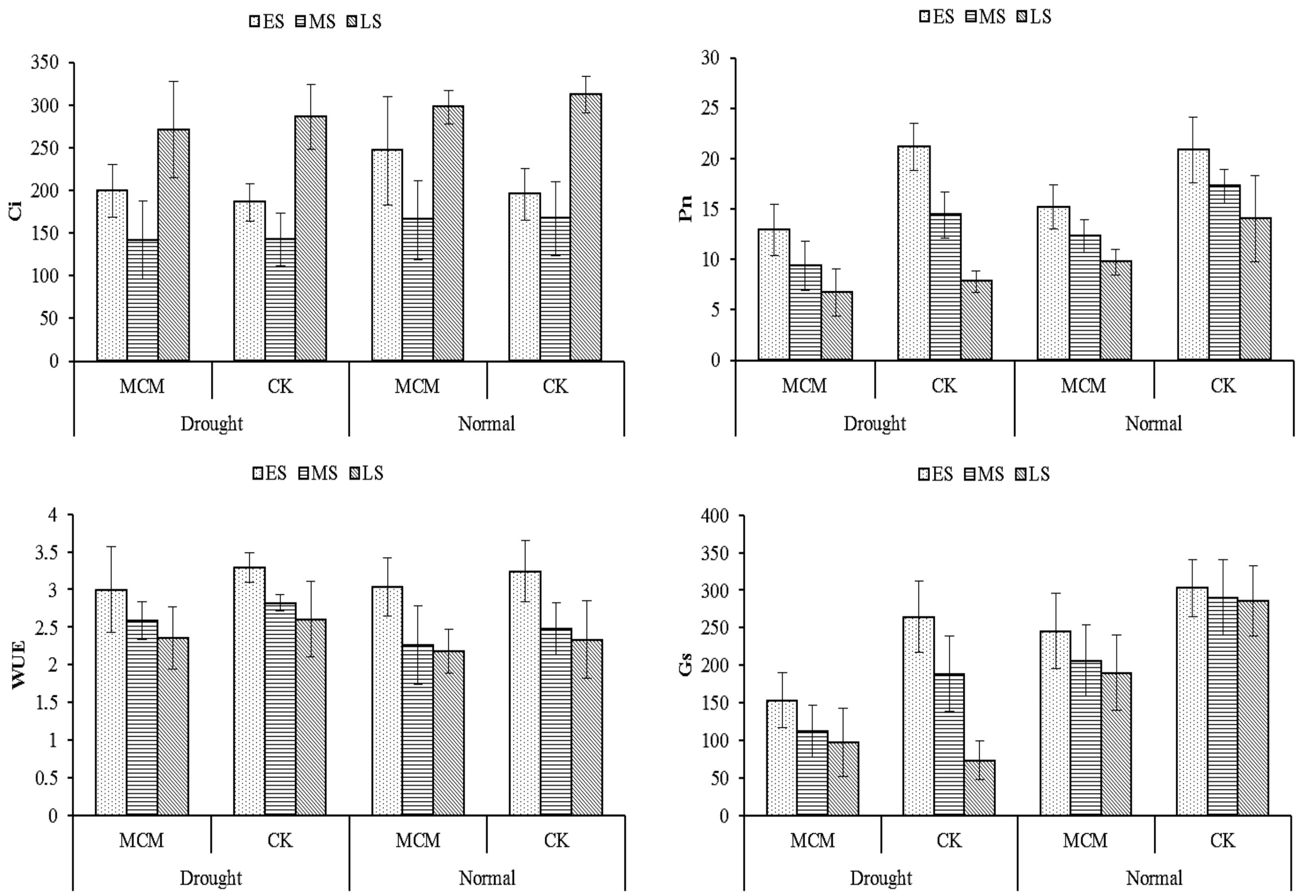

Fig. 1. Photosynthetic changes of flag leaves.
Note: Drought indicates drought treatment, and Normal indicates normal irrigation. ES represents the early stage of grouting, MS represents the middle stage of grouting, and LS represents the late stage of grouting.

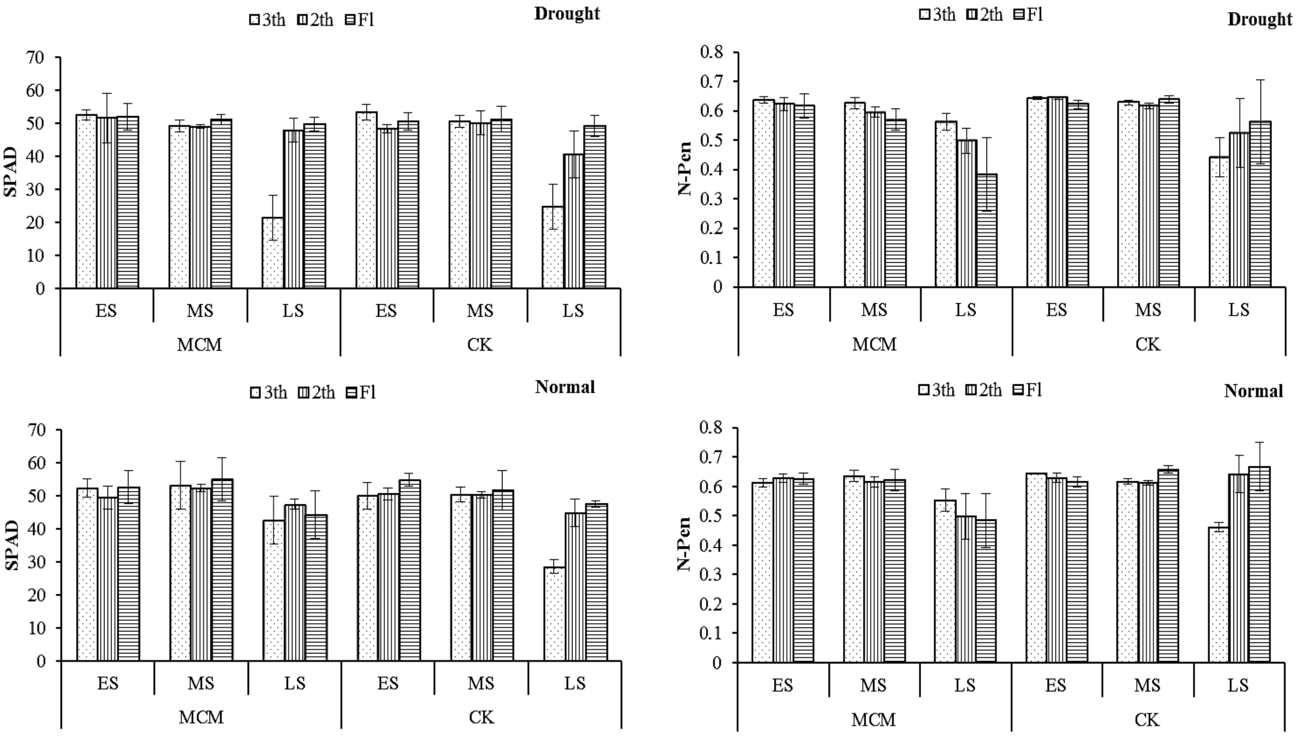

Fig. 2. Changes of chlorophyll and nitrogen content in three leaves.

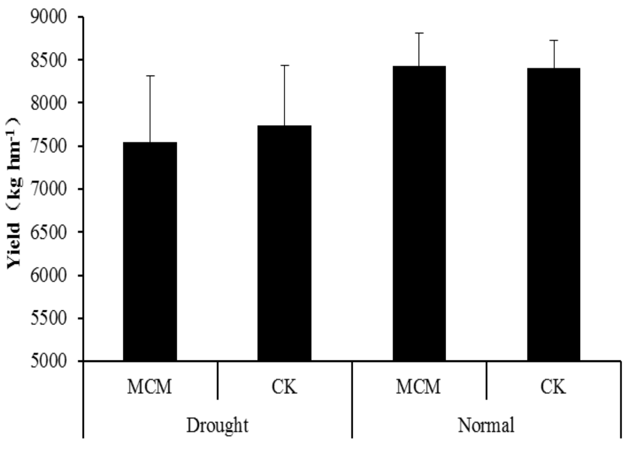

Fig. 3. Yield of different treatments.

Remarks: FL represents the top flag leaf, 2th represents the inverted second leaf and 3th represents the third leaf.

Changes of chlorophyll and nitrogen content in upper three leaves: As shown in (Fig. 2) SPAD values of the upper three leaves decreased gradually during different periods of grouting stage. Under drought conditions, there was no significant difference between MCM and CK, but under normal conditions, SPAD values of the second and third leaves treated by MCM in LS period were higher than those treated by CK.

There was no significant difference in nitrogen content in the upper three leaves under different water conditions at ES and MS stages, but in the LS stage, nitrogen content in different leaf positions increased gradually from bottom to top under CK treatment, while it decreased gradually under MCM treatment.

Based on the above analysis, MCM can affect the changes of chlorophyll and nitrogen contents in different leaf positions, but the influence degree is more obvious in the later stage of grout filling.

Yield of wheat under different treatments: As shown in (Fig. 3) under normal irrigation conditions, MCM yield is slightly higher than CK, but under drought conditions, MCM yield is slightly lower than CK, and the yield under normal irrigation treatment is significantly higher than that under drought treatment. Therefore, 1g/L MCM treatment had no significant effect on wheat yield under normal irrigation conditions, and even showed a downward trend under drought conditions.

Seed quality of wheat under different treatments: As shown in (Fig. 4) compared with CK, MCM treatment has different effects on grain water content, protein content and starch content under different water conditions. First of all, the grain water content under normal irrigation was higher than that under drought condition, while the decrease of grain water content under normal irrigation under MCM treatment was slightly larger than the difference between the two under drought condition. Secondly, although the protein content of MCM and CK under normal irrigation is basically the same, both of them are higher than that under drought, especially under drought condition, the protein content of MCM treatment is higher than that of CK. Finally, contrary to the change of grain protein content, the starch content of MCM under normal irrigation is basically the same as that of CK, but the starch content of MCM under drought condition is lower than that of CK. In conclusion, exogenous MCM treatment in early flowering period can effectively increase grain protein content under drought conditions, but reduce starch content.

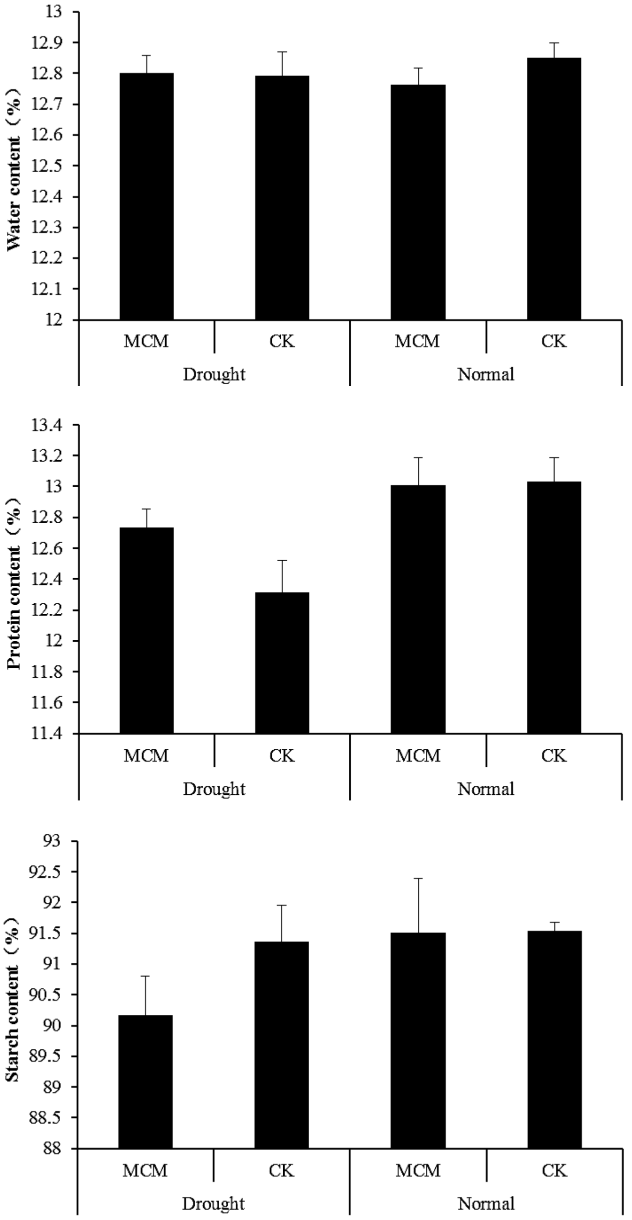

Fig. 4. Different treatments grain quality formation.

Discussion

Wheat is one of the three main grain crops in the world, and its yield directly affects the global food supply. Drought is one of the major stress disasters affecting wheat cultivation and production. Therefore, effectively improving wheat stress resistance in favour of promoting wheat grain yield and quality (Qamar *et al*., 2014). It is of great practical importance to global human development (Malko *et al*., 2022). With the progress of science and technology and social development, it has become a global consensus to effectively reduce input and improve resource utilization efficiency in agricultural production. As the most widely existed substance in nature, silicon is abundant and has good mechanical processing value. It is an essential substance for crop growth and development and an efficient nano-transport carrier for precise delivery of drugs(Etesami *et al*., 2022). Therefore, the research on nano silicon, especially in the field of crop resistant cultivation, will have an important impact on crop efficient cultivation and production.

Exogenous silicon can affect crop photosynthesis, and thus affect crop yield formation. Marlys Ulloa *et al*. showed that under the condition of phosphorus deficiency, 2 mM exogenous silicon could not only improve the composition of wheat cell wall, but also promote the utilization of carbon dioxide in leaves, thus promoting the increase of wheat net photosynthetic rate(Ulloa *et al*., 2021). Yi ZHANG *et al*. also showed that, Silicon increases the chlorophyll and carotenoid content of the tomato seedling in drought, contributing to the increase in the maximum photochemical efficiency (Fv/Fm), effective quantum efficiency, actual photochemical quantum efficiency (ϕPSII), photosynthetic electron transfer rate (ETR), and photochemical quenching coefficient (qP) of the chlorophyll fluorescence parameter. Thus, photosynthesis of tomato seedlings under drought conditions was improved, and substance accumulation and nutrient composition synthesis of seedlings were promoted (Zhang *et al*., 2018). However, in this study, there was a difference between the intercellular carbon dioxide concentration and water content at different stages of leaf spraying MCM grouting, but the net photosynthetic rate decreased. In the final yield stroke, there was no significant difference under normal irrigation treatment, while the yield decreased under drought condition, which was speculated to be related to the application concentration of silicon. That is, exogenous silicon can affect the change of wheat photosynthesis, but the promotion effect of low concentration silicon treatment on photosynthesis is not obvious.

Silicon can effectively affect photosynthetic pigment content and nitrogen accumulation and transport of crops, thus affecting grain yield and quality formation. Remi Chakma *et al*., showed that there was a correlation between soil moisture moderation and silicon application amount, and under the condition of adequate 100% and moderate 75% soil moisture fluctuation, planting grape or tomato seeds in 0.25 mM MSA or 300 kg ha-1 soil could increase grape or tomato yield. However, when soil moisture is lower than 50%, the improvement effect of silicon on yield and quality is not obvious (Chakma *et al*., 2021). Xiangnan Xu *et al*., showed that the application of exogenous silicon can effectively promote the increase of photosynthetic pigment content, improve nitrogen utilization, and thus enhance leaf photosynthesis. The accumulation of nutrients such as amino acids and sugars in fruits was promoted, and the effect of root silicon spraying was better than that of foliar spraying at the early growth stage of strawberry, while exogenous silicon spraying at the later growth stage of strawberry could also effectively improve the fruit yield and quality (Xu *et al*., 2023). The results of this study were similar. Although the contents of photosynthetic pigment and leaf nitrogen did not change significantly at the early or middle stage of filling under different irrigation conditions after MCM spraying at the flowering stage, significant changes occurred at the late stage of filling, especially the changes of nitrogen content in the upper three leaves. Therefore, it was concluded that exogenous silicon could effectively improve leaf photosynthetic pigment content and regulate leaf nitrogen content. But the effect is more obvious in the middle and late grout.

Conclusion and Prospect

The results of this study showed that spraying mesoporous silica at the flowering stage could affect the photosynthesis of wheat leaves and regulate the nitrogen utilization capacity of wheat at the filling stage, and the effect was more obvious at the late filling stage, thus affecting the formation of wheat grain yield and quality. However, it should also be pointed out that the drought resistance of plants induced by exogenous silicon is affected by the degree of drought and the amount of silicon. In this study, the changes of different physiological metabolism, especially the changes of photosynthesis, do not meet the expectations, which is speculated to be related to the excessive degree of drought and the insufficient amount of silicon.

Acknowledgment

National Key Research and Development Program, No.2022YFD2300803; Independent Innovation Project of Henan Academy of Agricultural Sciences, No.2023ZC003; Central Plains Science and Technology Innovation Leading Talents Program, No.224200510028; Henan Province Modern Agricultural Industrial Technology System Construction Special Project, No.HarS-22-01-G5; Science and Technology Innovation Team, Henan Academy of Agricultural Sciences, No.TD202407.

References

Ashkavand, P., M. Tabari, M. Zarafshar, I. Tomásková and D. Struve. 2015. Effect of SiO2 nanoparticles on drought resistance in hawthorn seedlings. *Leśne Prace Badawcze*, 76(4): 350-359.

Chakma, R., P. Saekong, A. Biswas, H. Ullah and A. Datta. 2021. Growth, fruit yield, quality, and water productivity of grape tomato as affected by seed priming and soil application of silicon under drought stress. *Agric. Water Manage*., 256: 107055.

Chen, H.Z., X.D. Xu and W.Z. Liu. 2022. Exogenously applied aluminum induced growth inhibition and apoptosis in wheat seedlings. *Pak. J. Bot.*, 54(1): 125-130.

Debaeke, P., P. Rouet and E. Justes. 2006. Relationship between the normalized SPAD index and the nitrogen nutrition index: application to durum wheat. *J. Plant Nutr.*, 29(1): 75-92.

Efretuei, A., M. Gooding, E. White, J. Spink and R. Hackett. 2016. Effect of nitrogen fertilizer application timing on nitrogen use efficiency and grain yield of winter wheat in Ireland. *Ir. J. Agric. Food Res*., 55(1): 63-73.

Elsheery, N.I., M.N. Helaly, H.M. El-Hoseiny and S.M. Alam-Eldein. 2020. Zinc oxide and silicone nanoparticles to improve the resistance mechanism and annual productivity of salt-stressed mango trees. *Agronomy*, 10(4): 558.

Etesami, H., Z. Li, F.J.M. Maathuis and J. Cooke. 2022. The combined use of silicon and arbuscular mycorrhizas to mitigate salinity and drought stress in rice. *Environ. Exp. Bot*., 201: 104955.

Gupta, J., M. Quadros and M. Momin. 2023. Mesoporous silica nanoparticles: Synthesis and multifaceted functionalization for controlled drug delivery. *J. Drug Deliv. Sci. Technol.*, 81: 104305.

Haris, M., T. Hussain, H.I. Mohamed, A. Khan, M.S. Ansari, A. Tauseef, A.A. Khan and N. Akhtar. 2023. Nanotechnology – A new frontier of nano-farming in agricultural and food production and its development. *Sci. Total Environ*., 857: 159639.

Khoroshilov, A., N. Pavlovskaya, D. Borodin and I. Yakovleva. 2021. A nanosilicon preparation is superior to a biological preparation and a chemical preparation in activity towards photosynthetic productivity and yield parameters of spring wheat. *Sel'skokhozyaistvennaya biologiya [Agricultural Biology]*, 56(3): 487-499.

Malko, M.M., A. Khanzada, X. Wang, A. Samo, Q. Li, D. Jiang and J. Cai. 2022. Chemical treatment refines drought tolerance in wheat and its implications in changing climate: A review. *Plant Stress*, 6: 100118.

Muhie, S.H. 2022. Novel approaches and practices to sustainable agriculture. *J. Agric. Food Res*., 10: 100446.

Qamar, M., S.D. Ahmad, M.A. Rabbani, Z.K. Shinwari and M. Iqbal. 2014. Determination of rust resistance genes in pakistani bread wheats. *Pak. J. Bot.*, 46(2): 613-617.

Siddiqui, M.H. and M.H. Al-Whaibi. 2014. Role of nano-SiO2 in germination of tomato (*Lycopersicum esculentum* seeds Mill.). *Saudi J. Biol. Sci*., 21(1): 13-17.

Tripathi, D.K., S. Singh, V.P. Singh, S.M. Prasad, N.K. Dubey and D.K. Chauhan. 2017. Silicon nanoparticles more effectively alleviated UV-B stress than silicon in wheat (*Triticum aestivum*) seedlings. *Plant Physiol. Biochem.*, 110: 70-81.

Ulloa, M., A. Nunes-Nesi, P. da Fonseca-Pereira, P. Poblete-Grant, M. Reyes-Díaz and P. Cartes. 2021. The effect of silicon supply on photosynthesis and carbohydrate metabolism in two wheat (*Triticum aestivum* L.) cultivars contrasting in response to phosphorus nutrition. *Plant Physiol. Biochem*., 169: 236-248.

Xie, Z.P. and J. Xu. 2009. A comparison of response curves of winter wheat photosynthesis to flag leaf intercellular and air CO2 concentrations. *Chinese J. Ecol*., 28(11): 2233.

Xu, X., G. Zou, Y. Li, Y. Sun and F. Liu. 2023. Silicon application improves strawberry plant antioxidation ability and fruit nutrition under both full and deficit irrigation. *Sci. Hortic*., 309: 111684.

Zhang, Y., Y. Shi, H.J. Gong, H.L. Zhao, H.L. Li, Y.H. Hu and Y.C. Wang. 2018. Beneficial effects of silicon on photosynthesis of tomato seedlings under water stress. *J. Integr. Agric*., 17(10): 2151-2159.

(Received for publication 01 July 2023)