original scientific paper
Ratar. Povrt. 2024, 61(3): 74-84
doi: 10.5937/ratpov61-48514
Manuscript submitted: 1 January 2024
Manuscript accepted: 15 October 2024

Evaluation of nitrogen fertilizer and nano silicon spray on seed yield performance and components of sunflower

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Summary: Considering the climatic altering and the noteworthy increment within the late seasonal dry stress on sunflower in semi-arid regions, it is fundamental to utilize modern administration like application nano silicon to reduce the unfavourable impacts of such stresses. A field trial was performed to study the effects of nitrogen levels (40, 80, and 120 kg ha^{-1}) and foliar spray treating of nano silicon (50, 100, and 150 ppm) on some traits of sunflower. The first two factors explained 79% of the variation and showed strong positive association of yield and thousand-seed weight. The N4-Si3 (120 kg ha^{-1} nitrogen plus 150 ppm nano silicon) indicated the higher values for most traits, leaf and head properties and seed yield. For confirmation findings of factor analysis, the clustering of traits and treatments was performed and categorized the measured traits and treatments into three clusters. The medium and high concentrations of nitrogen and nano silicon (80 and 120 kg ha^{-1} nitrogen; 100 and 150 ppm nano SiO_2) were grouped with each other in the same cluster and were the best treatments. The nitrogen is one of the important fertilizers for sunflower production and low magnitudes of nitrogen could not be sufficient in semiarid environments. The nano silicon has beneficial ability to minimize the harmful influences of environmental stresses and can provide the goals of sustainable and low-input agricultural systems in production of sunflower under semi-arid regions.

Keywords: fertilization, nano silicon, nitrogen, seed yield, semi-arid regions, sunflower

Introduction

Oilseed derivatives serve as vital contributors to the human energy supply, with sunflower seeds standing out prominently in this regard, comprising 44% of their content, and they account for around 10% of the global edible oil output (Hristova-Cherbadzhi, 2023). In Iran, sunflower holds the third position in oil production, following soybean and oilseed rape whereas its ten-years average harvested area and yield is about 57 thousand ha and 968.4 kg ha^{-1}, respectively (Table 1). In the world, the cultivated area for sunflowers spans an estimated about 30 million hectares, yielding a substantial 58 million tons of achenes. While sunflower generally exhibits significant adaptability to diverse climatic conditions, the subdued yield observed in semi-arid regions like northeastern Iran can be ascribed to various factors (Sabaghnia & Janmohammadi, 2023). These include unsuitable soil conditions, deficiencies in essential nutrients, the practice of cultivating sunflowers as a second crop following the harvesting of winter cereals such as wheat and barley, exposure to sensitive reproductive phases coinciding with hot and dry periods, inconsistent fertilization practices, and suboptimal nutritional management.

Table 1. The ten years statistics of areas and yields of sunflower in Iran from FAOSTAT

Year	Value	Unit	Value	Unit
2013	10293	100 g/ha	62402	ha
2014	6443	100 g/ha	24083	ha
2015	9791	100 g/ha	43905	ha
2016	10000	100 g/ha	65000	ha
2017	10000	100 g/ha	64000	ha
2018	10000	100 g/ha	63000	ha
2019	10000	100 g/ha	62000	ha
2020	10000	100 g/ha	61000	ha
2021	10000	100 g/ha	60000	ha
2022	10317	100 g/ha	63000	ha
Mean	9684.4	100 g/ha	56839	ha

Nitrogen stands out as a pivotal and highly influential mineral element in plant physiology, directly impacting plant growth. Comprising approximately 3% of the plant's dry weight, nitrogen holds significant importance relative to other mineral elements regarding its structural role in amino acids, a deficiency in nitrogen can profoundly influence the function and structure of enzymatic proteins (Kaur et al., 2017). The availability of nitrogen in the soil and its absorption by the plant's root system play a pivotal role in influencing the rate of photosynthesis, the provision of photo-assimilates, and, by extension, the production of oil in the sunflower achene. Nevertheless, nitrogen deficiency poses a challenge to the soil in semi-arid regions. Effective nitrogen management, involving timely and appropriate applications, emerges as a potential solution to enhance both sunflower growth and the quantity and characteristics of the extracted oil (Vejan et al., 2021). The response of sunflower growth and achene production exhibits variability with different nitrogen fertilizer doses, and the rate of nitrogen application plays a crucial role in nitrogen use efficiency and the absorption efficiency of other elements. Among various nitrogen application levels, the utilization of 90 kg of nitrogen has been reported to enhance the efficacy of fertilizers containing micronutrients (Dimkpa et al., 2020).

Silicon stands as a non-essential yet abundant element in soil, and while not indispensable for growth, it remarkably influences plant development. In the soil, silicon exists in a form invisible to the root system, but plants can exclusively absorb it from the rhizosphere in the form of ortho-silicic acid. Intriguingly, silicon is unique in that it does not exert serious harmful effects even when it accumulates excessively in plant tissues (Pang et al., 2023). Silicon plays crucial roles in inducing defence mechanisms against pathogens, supporting seedling establishment, enhancing cell wall elasticity and strength, and reducing transpiration. Silicon has demonstrated positive and promising effects on the activity of superoxide dismutase enzymes and peroxidase enzyme activity (De Sousa et al., 2019). The utilization of silicon may amplify the positive impact of certain macronutrients, such as nitrogen and phosphorous. The multifaceted contributions of Si extend beyond its non-essential status, revealing its potential as a valuable element in promoting plant health and resilience in challenging environmental conditions.

Given the soil limitations prevalent in semi-arid regions, the application of silicon through spraying emerges as a potential solution to meet the plant's requirements and stimulate its defence systems. Incorporating nanotechnology in this process can be particularly impactful. The external application of silicon in nano dimensions proves advantageous due to its larger external surface area and specific physical and chemical properties compared to bulk particles, thereby enhancing the efficiency of silicon's effects (Huang et al., 2021). Nanoparticles exhibit adjustable reactivity and bioavailability, making them more effective even at low concentrations due to their slow and steady release and targeted delivery, a feature not as pronounced in bulk fertilizers. Nano silicon, owing to its small size, can be readily absorbed by plants and easily traverses barriers such as cell walls and membranes. In contrast to bulk form, nano silicon is more accessible for loading and distribution within the vascular system. Despite these advantages, there is currently limited information about the impact of nitrogen dosage and foliar spraying of varying concentrations of silicon dioxide nanoparticles under semi-arid conditions (Sabaghnia et al., 2018; Ding et al., 2023). This investigation was specifically designed and executed to explore the effectiveness of nano silicon under different nitrogen fertilizer applications on the growth performance of sunflower plants. The research aims to contribute valuable insights into optimizing the use of nano silicon in conjunction with nitrogen for sunflower cultivation in challenging semi-arid environments.

Material and Methods

Field Area

The investigation was performed in the Hashtroud region of East Azarbaijan, Iran during the season 2023. The field soil was identified as a silt loam, with 70% silt, 20% sand, and 10% clay. The total rainfall recorded during the growing season amounted to 71 mm.

Experimental Design

The design was a factorial structure with a control, based on a randomized complete block design featuring three replications. The nitrogen factor involved varying nitrogen levels (40, 80, and 120 kg ha^{-1}), while the nano silicon factor encompassed different concentrations of foliar spray of nano SiO_2 (50, 100, and 150 ppm).

Performing of Trial

The seeds of Khoi variety were undergoing sterilization before planting with immersing them in a 5% sodium hypochlorite solution for 10 minutes for accurate surface sterilization, then three times washing was performed via distilled water. Initial tillage of the field occurred in the autumn of 2022, utilizing a moldboard plow, and in the early spring of 2023, secondary tillage activity was conducted using a disc, rotavator, and leveller. The distance between the ridges was set at 0.7 m, with a 0.2 m spacing between plants within each row for 8 rows with 4 m length. Immediate irrigation followed the planting process, facilitated through polyethylene pipes and a drip tape system. In the later stages of development, irrigation frequency was adjusted to every 4 to 7 days, taking into consideration climatic conditions and the specific water requirements of the sunflower plants.

Treatments' Application

Foliar spraying of nano silicon was strategically conducted at three distinct stages of sunflower growth (stem development, elongation of buds, and flowering starting). To optimize nitrogen utilization, a split nitrogen consumption method was implemented. One-third of the nitrogen was applied during seed sowing, another third during the vegetative growth phase, and the remaining portion during early reproductive growth.

Traits

For the assessment of yield components, 10 plants were carefully harvested from each plot at full maturity. The measured traits included PH (plant height), SD (stem diameter), LN (leaf number), LL (leaf length), LW (leaf width), CW (canopy width), HD (head diameter), HW (head weight), AH (number of achenes per head) and EA (empty achenes). To evaluate the final seed and biological yield, a defined area of 3 square meters was harvested and SY (seed yield) and BY (biological weight) were determined from that harvested area. From three subsamples, TSW (thousand-Achene weight) was recorded.

Statistical analysis

The normal distribution of dataset was assessed by the Ryan-Joiner test. The factor analysis was used for the decrease of associated traits to a small number of factors and varimax rotation was applied. For graphical illustration of associations, the scores of first two factors were plotted each other. Also, for simultaneous presentation of treatments and traits in a single graph, a biplot was generated using symmetrical scaling. Finally, treatments and traits were clustered by their distance from each other using Squared Euclidean Distance and clustered by Ward's method. The cutoff point for determine the number of final clusters was verified using λ statistic of multivariate ANOVA.

Results and Discussion

Factor Analysis

Factor analysis indicated that the first two factors explained 79% of the total variation in sunflower traits under various treating conditions (Figure 1) and the relationships among them can be understood through the vectors of each trait in middle of the chart. The longitude of each line represents the linkage bias, and the cosine of the angle of the lines are the magnitude of traits' association. The angle of straight lines represents absence of connection (cos 90°=0), the angle of opposite lines represents negative connection (cos 180°= -1) and the angle of closed lines represents a positive association (cos 0°= + 1). From Figure 1, LW, CW and BY as well as SY and TSW, and similarly HD, AH, LN, HW, PH and LL were positively associated and showed relatively the same information about response of sunflower to the treatments. Most of the above traits were related to yield components like diameter and weight of heads as well as weight and number of achenes, so improving one of them can increase the other related traits results in higher yield performance. Our findings were in good compromise with those mentioned by Mahmood (2021), who reported achene yield had positive association with diameter and weight of head, number and weight of achene, harvest index and biological yield and increasing of these components by appreciate fertilizer application as well as application of nano silicon for confrontation of late seasonal stresses like water shortage cause to increase in achene yield. Regarding the right lines' angle of SD (stem diameter) and EA (empty achenes), there is not any significant association between these traits (Figure 2). According to Kanwal et al. (2019), and Koutroubas et al. (2020), stem diameter and empty achenes of sunflower have not any association while they had weak positive association with the traits. According to Turchetto et al. (2021), thousand-seed weight is positivity associated with the head diameter whereas large head can fill seeds in a longer time, similar to those found in this investigation.

Biplot Analysis

For concurrent assessment of sunflower traits with treatments, biplot, a scatter-plot with signs of treatments and traits for indicating data structure was drawn (Figure 2), which reports scores of individuals and variables in a plot, so fertilizers can be studied for their effects on traits. Thus, N_4-Si_2 treatment produced high amounts empty achenes while N_2-Si_2 and N_3-Si_3 treatments caused thicker stem diameter (Figure 2). The N_4-Si_3 treatment followed by N_3-Si_4 treatment indicated the higher values for the other remined traits, PH, LN, LL, LW, CW, HD, HW, AH, TSW, SY and BY (Figure

2). So, it seems using higher concentration of nitrogen fertilizer (80 and 120 kg ha^{-1}) as well as nano silicon (100 and 150 ppm) can help sunflower grow better and produce more yield performance as well as more yield components. Medium and high magnitudes of nitrogen increased the growth and yield of sunflower while application of small magnitudes of nitrogen or nano silicon did not have a significant effect. Therefore, application of such nitrogen concentrations, can increase the effectiveness of silicon dioxide nanoparticles. Although, some investigations have shown the effectiveness of external application of silicon nanoparticles under harsh climatic conditions (El-Saadony et al., 2021), the results of current research indicate that the utility of silicon dioxide can be largely influenced by the management conditions especially the supply of essential elements.

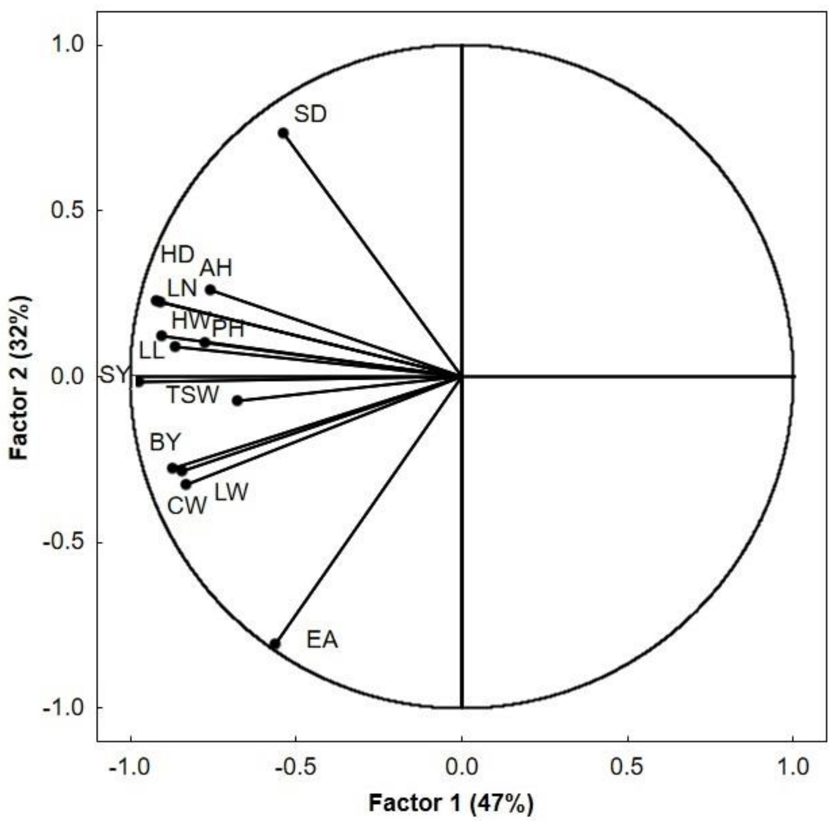

Figure 1. Plot of first two factors indicating the relationships among characteristics of sunflower. Characteristics are PH (plant height), SD (stem diameter), LN (leaf number), LL (leaf length), LW (leaf width), CW (canopy with), HD (head diameter), HW (head weight), AH (number of achenes per head), TSW (thousand-achene weight), EA (**e**mpty achenes), SY (seed yield) and BY (biological weight).

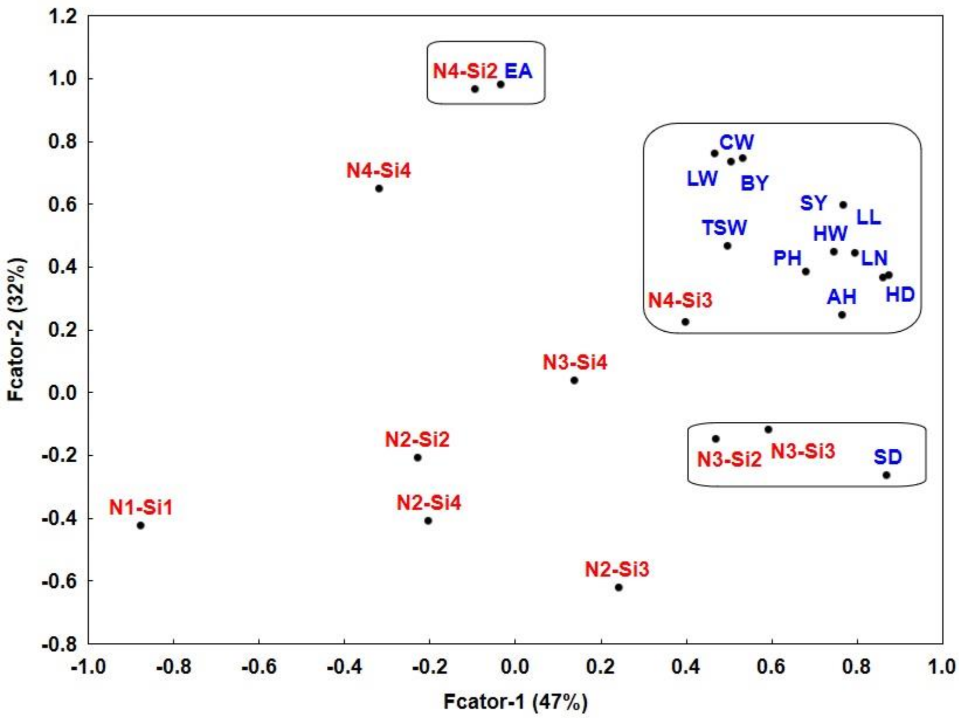

Figure 2. Biplot of first two factors indicating the relationships among fertilizer treatments and traits in sunflower. Characteristics are PH (plant height), SD (stem diameter), LN (leaf number), LL (leaf length), LW (leaf width), CW (canopy with), HD (head diameter), HW (head weight), AH (number of achenes per head), TSW (thousand-achene weight), EA (empty achenes), SY (seed yield) and BY (biological weight).

Traits' Clustering

For confirmation above obtained findings, the clustering of traits and treatments as an agglomerative hierarchical model was performed and the thirteen traits of sunflower can be categorized into three clusters (Figure 3) which determined by λ statistic of Wilks of multivariate ANOVA (λ=0.0013, $p<0.01$). In this dendrogram, Cluster-I consist on PH, CW, BY, LW, EA and TSW while Cluster-II contains LN, HD, HW, LL and SY; and Cluster-III consist on SD and AH traits (Figure 3). While it is expected that most results of factor and cluster analyses can be confirmed from each other, but some results were not consistent because the factor analysis described only 79% of the variation and 21% was remined for the next factors, but the overall results were in agreement with the cluster analysis which used 100% of variance. Finally, both models indicated visual grasp on the data structure, which is more practical than the univariate models. However, the influence of LN (leaf number), LL (leaf length), HD (head diameter) and HW (head weight) on final seed yield of sunflower was verified through both factor and cluster analyses. Number and length of leaves have an important effect on yield due to their role in sunlight attraction, because leaf is the unique organ for sunlight competing and can increase the photosynthesis and crop growth (Zhang et al., 2020). The head diameter affects the number of flowers and seeds in the plant heads, so influences the sunflower yield performance (Lagiso et al., 2021). Our results verified the above report about the role of sunflower head diameter on yield, however, such influence related to cultivar type and growing circumstances, as well as their interactions. The leaf characteristics was influenced by environmental circumstances such nutrient shortage, this phenomenon being in agreement with the fact that crops under stressful conditions reduce leaf growth similar to yield components, which were affected by the stressful circumstances.

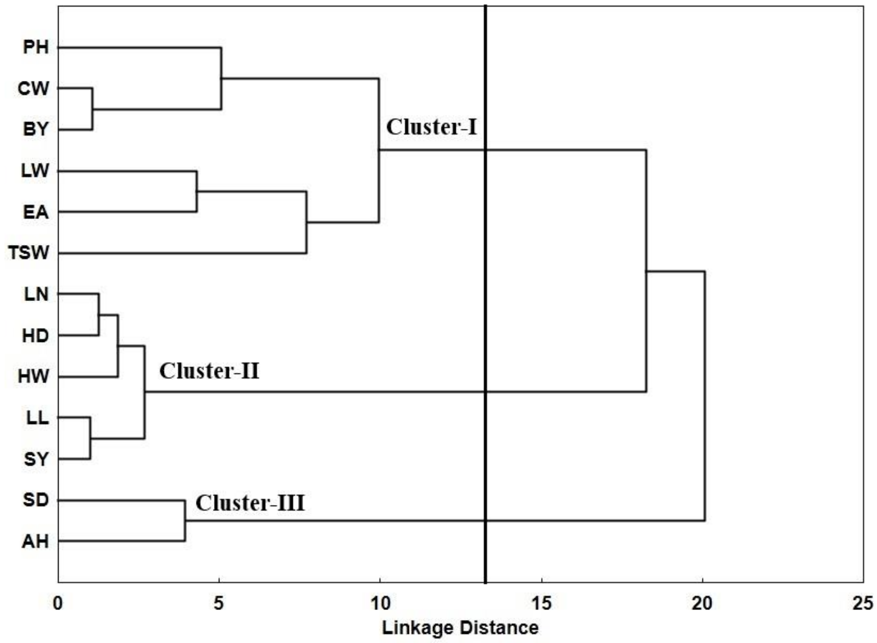

Figure 3. Dendrogram of cluster analysis indication the grouping of characteristics of sunflower. Characteristics are PH (plant height), SD (stem diameter), LN (leaf number), LL (leaf length), LW (leaf width), CW (canopy with), HD (head diameter), HW (head weight), AH (number of achenes per head), TSW (thousand-achene weight), EA (empty achenes), SY (seed yield) and BY (biological weight).

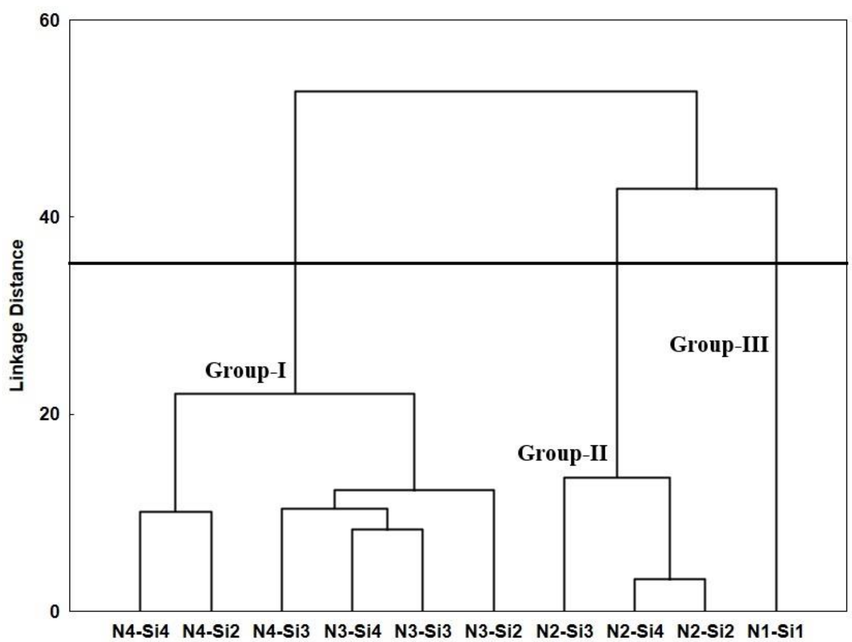

Figure 4. Dendrogram of clustering indicating the grouping of treatments

Treatments' Clustering

The ten treatments could be categorized into three clusters via confirmation of λ statistic of Wilks in multivariate ANOVA (λ=0.0024, p<0.01). In dendrogram of Figure 4, Group-I was consisting on N_3-Si_2, N_3-Si_3, N_3-Si_4, N_4-Si_2, N_4-Si_3 and N_4-Si_4; Group-II was consisting on N_2-Si_2, N_2-Si_3, N_2-Si_4; and Group-III was consisting on Control or N_1-Si_1. Similar to traits, clustering of treatments verified sone of the results of factor analysis in Figure 2, whereas the Control and low concentrations of nitrogen and nano silicon (40 kg ha^{-1} nitrogen and 50 ppm nano SiO_2) were grouped as distinct clusters while the medium and high concentrations of nitrogen and nano silicon (80 and 120 kg ha^{-1} nitrogen; 100 and 150 ppm nano SiO_2) were grouped with each other in the same cluster. Our results are consistent with foliar application of nano silicon dioxide on safflower which reported, the positive effect was seen under improved nutritional conditions and the application of only nano silicon was not effective under no fertilizer condition (Janmohammadi et al., 2016).

Radar Plot

The means of traits for treatments were indicated via radar plot (Figure 5), and it can be indicated that the N_3-Si_2 treatment was the best for SD, AH and TSW traits while the N_3-Si_3 treatment was the best for LN, LL, HD, HW and SY traits. Also, the N_4-Si_2 treatment was the best for LW, CW and EA traits while the N_4-Si_3 treatment was the best for BY, PH and CW traits. In other word, for obtaining the grater CW (canopy with), we can use both concentration of nano silicon (50 and 100 ppm) while for reach to the higher SY (seed yield), we must use only N_3-Si_3, 80 kg ha^{-1} nitrogen and 100 ppm nano SiO_2 (Figure 5). Such details are missed in multivariate analysis and they gave general grasp from data pattern.

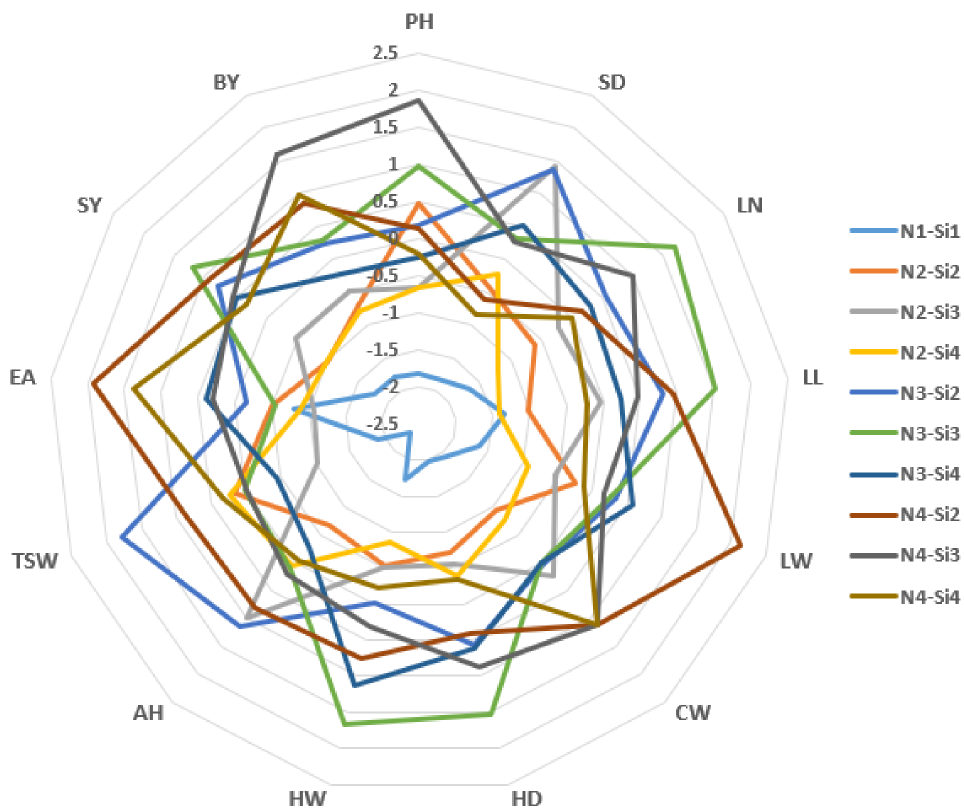

Figure 5. Radar plot indicating the performance of treatments in measured characteristics of sunflower

Considering the soil conditions in the semi-arid areas and regarding the problems in the supplying and absorption of required elements, foliar spraying of nano silicon may have positive effects on crops. Application of nitrogen increases vegetative growth and may result in water shortage through transpiration, and led to some restriction in in the semi-arid areas. However, our findings emphasized that using sufficient nitrogen (80 or 120 kg ha^{-1}) and foliar spray of silicon dioxide nanoparticles (100 ppm), growth and yield performance improved in a logical mood. Regarding the protective potential of nano silicon, the application its proper concentration is important due to the fact that sunflower growth coincides with hot and dry summer periods in semi-arid Mediterranean regions. The effectiveness of nano silicon nanoparticles still requires more studies, however, our results showed positive and synergistic interactions between nitrogen fertilizer and nano silicon.

Comparison of Findings

Semi-arid areas typically face challenges related to water availability and soil quality. In such regions, the soil may have limited water retention capacity, and the availability of essential nutrients for plant growth might be compromised, so it sets the stage for exploring alternative strategies to enhance crop productivity (Ayangbenro & Babalola, 2021). Foliar spraying involves applying nutrients directly to the leaves of plants. The choice of nano silicon for this purpose is interesting. Nanoparticles often exhibit unique properties due to their small size, which may enhance their penetration through the leaf cuticle and improve nutrient uptake by plants. Our research suggests that nano silicon, when applied in this manner, can potentially address nutrient deficiencies in crops grown in semi-arid conditions. The potential downside mentioned in the paper is the increased transpiration, which could exacerbate water shortage issues in semi-arid regions. This highlights the need for a balanced approach to nutrient application, considering both growth promotion and water use efficiency (Ullah et al., 2019).

The discussion on the optimal concentrations of nitrogen and nano silicon is significant. Finding the right balance is crucial to maximizing the benefits without causing unintended negative effects. The mention of sunflower growth patterns in relation to hot and dry summer periods emphasizes the need for agricultural practices that align with the specific environmental conditions of the region. Understanding the phenology of crops and tailoring nutrient applications accordingly is essential for successful cultivation (Potgieter et al., 2021). The protective potential of nano silicon is intriguing. It hints at the possibility of nano silicon serving a dual role, not just as a nutrient source but also as a protective agent, possibly against environmental stressors such as high temperatures and drought, which are common in semi-arid regions. The observed positive and synergistic interactions between nitrogen and nano silicon underscore the complexity of nutrient interactions in plant physiology. This finding suggests that the combined application of these elements may have a more significant impact than when applied individually. Understanding these synergies can contribute to the development of more effective crop management strategies.

More studies are needed indicates a recognition of the complexity of the interactions between nano silicon, nitrogen, and crops. Future research can explore additional aspects such as long-term effects, environmental impacts, and the scalability of the proposed approach. In conclusion, the research highlighted a promising avenue for improving crop productivity in semi-arid areas through the strategic application of nano silicon and nitrogen. However, it also emphasized the need for a nuanced and context-specific approach, considering the unique environmental and growth conditions of the region. Ongoing research will likely refine our understanding and guide the development of practical, sustainable agricultural practices for these challenging environments.

Conclusion

We found the best efficient fertilizer application to ameliorate yield and yield components of sunflower is using N_3-Si_3 (80 kg ha^{-1} nitrogen and 100 ppm nano SiO_2). Similarly, using other concentrations did not show any considerable effect on sunflower traits or had harmful effects. We found the useful influence of nano silicon on late seasonal stress, but more research is needed to study the other aspects of nanoparticles and determine their interactions with plant, soil and other factors.

Author contributions: Both authors contributed equally to this article.

Acknowledgments: We thank our colleague Dr. Mojtaba Amini (University of Tabriz, Iran) for description of nanoparticles.

Competing interests' statement: No competing interests were disclosed.

Funding statement: This research received no external funding.

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Procena primene azotnog đubriva i nano-silicijum spreja na performanse i komponente prinosa semena suncokreta

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Sažetak: Uzimajući u obzir klimatske promene i značajan porast u okviru stresa suše na suncokret u kasnoj sezoni u polusušnim oblastima, od suštinske je važnosti da se koristi moderna primena nano-silicijuma da bi se smanjili nepovoljni uticaji takvog stresa. Sproveden je poljski ogled radi proučavanja efekata nivoa azota (40, 80 i 120 kg ha^{-1}) i tretmana folijarnog prskanja nano-silicijuma (50, 100 i 150 ppm) na neke osobine suncokreta. Prva dva faktora su objasnila 79% varijacije i pokazala snažnu pozitivnu povezanost prinosa i mase hiljadu semena. N_4-Si_3 (120 kg ha^{-1} azota plus 150 ppm nano-silicijuma) ukazuje na više vrednosti za većinu osobina, svojstva lista i glavice i prinos semena. Za potvrdu nalaza faktorske analize, izvršeno je grupisanje osobina i tretmana, a merene osobine i tretmani su kategorizovani u tri klastera. Srednje i visoke koncentracije azota i nano-silicijuma (80 i 120 kg ha^{-1} azota; 100 i 150 ppm nano SiO_2) grupisane su jedna sa drugom u isti klaster i predstavljale su najbolji tretman. Azot je jedno od važnih đubriva za proizvodnju suncokreta i male količine azota ne mogu biti dovoljne u polusušnim oblastima. Nano-silicijum ima blagotvornu sposobnost da minimizira štetne uticaje ekoloških stresova i može da obezbedi ciljeve održivih poljoprivrednih sistema sa niskim unosom u proizvodnji suncokreta u polusušnim oblastima.

Ključne reči: azot, đubrenje, nano-silicijum, polusušne oblasti, prinos semena, suncokret