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Research Article

Growth, Physiological Responses and Yield of Maize (*Zea mays* L.) to Silica Nanoparticles Application at Different Growth Stages

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Abstract— The experiment was conducted to investigate the effect of nano-silica application methods on the growth, physiological responses and yield of maize (*Zea mays* L.). The field experiment was conducted at the Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi, from November 2021 to April 2022. Silica nano powder (<100 nm particle size (TEM), ≥98% trace metals basis) was brought from Sigma-Aldrich was used for this experiment. The experiment consists of two nano Si application periods as 8-10-leaves stage or early stage, E and taselling stage or late stage, L and in four nano-silica application methods as soil application, SA; foliar application, FA, soil application + foliar application, SA+FA and control or without silica application, CK. Treatments were replicated three times and arranged in Randomized Complete Block Design (RCBD). Standard irrigation and fertilization schedule as well as other cultivation procedures were followed during the experiment. Results revealed that most of the growth characters (plant height, leaf area, total dry matter production and crop growth rate), physiological parameters (relative leaf water content, canopy cover and chlorophyll content) yield contributing characters (cob length, number of grains cob^{-1}, 1000-grain weight, stover yield and biological yield) and yield (grain yield) was highest for early stage nano silica application, and the values are much effective with foliar application. Highest grain yield (6.82t ha^{-1}), stover yield (8.92t ha^{-1}) and biological yield (15.74t ha^{-1}) were found at early nano silica application. Considering application methods highest cob length (29.10cm), no of grain per cob^{-1} (562.1), 1000 grain weight (296.2 gm), grain yield (6.91t ha^{-1}), stover yield (8.66t ha^{-1}), biological yield (15.57 t ha^{-1}) and harvest index (44.39%) was found for foliar application method. The interaction effect of nano Si application stage and application methods did not show any significant influence except no. of grains cob^{-1} and grain yield. Considering maximum progressive response in maize. it can be recommended that foliar application of nano Si (@15 kg/ha) at the early growth stage (8-10 leaf stage) would be the best practice for maize production in experimental areas.

Keywords— nano silica; maize growth; Canopy cover; leaf color code.

1. Introduction

Nanotechnology is revolutionizing agriculture and food production, potentially dramatically modifying existing agricultural practices. The majority of agrochemicals used on crops are lost and do not reach their intended destination due to a variety of causes, including leaching, drifting, hydrolysis, photolysis, and microbiological degradation. Nanoparticles can be used to encapsulate and deliver nutrients, fertilizers, and pesticides to plants more efficiently. This targeted delivery system can reduce waste, and improve nutrient uptake. Therefore, several nano compounds have recently piqued the interest of agricultural researchers, and nano-silicon (nSi) is one of the useful nanomaterials for crop production, as reported by several authors.

Silicon is not considered an essential major nutrient for most plants, but it is beneficial and can be accumulated in plants at higher concentrations than some essential nutrients. Silicon is regarded as a "beneficial element" because it can improve plant growth, health, and resistance to various stresses. While silicon is not required for all plants to complete their life cycle, many plants can take up and accumulate silicon when it is available in the soil [2].

It promotes upright stature, prevents lodging, increases leaf exposure to light, provides resistance to bacterial and fungal diseases [3], salinity [4] heavy metal toxicity [5] and influences the accumulation of nitrogen, phosphorus, and other essential elements in plant tissue [6]. Not only has silicon supply been effective in the rhizosphere, but silicon supplementation in the form of external foliar treatments has also proven to increase the pathogen resistance of plant species [7]. Most soils contain significant amounts of this element, but repeated cropping can reduce plant-available Si levels to the point where supplemental Si fertilization is required to maximize crop yield [8].

Nano silica is more reactive than bulk silica, thus it is regarded as a novel approach for plant growth. Smaller quantities of silica nanoparticles (SNPs) would be effective in improving crop growth and development [9]. Nano silica can improve plant root absorption of essential nutrients such as silicon (Si) as well as other macro and micronutrients, resulting in increased plant growth. However, silicon-deficient plants are often structurally weaker with abnormal growth and more susceptible to biotic and abiotic stresses than Si-rich plants. Nano silica can be used as a foliar spray or a soil amendment. Both methods have advantages and disadvantages, and the type of nanoparticles, crop requirements, and soil type frequently determine the best approach. However, foliar application allows for targeted delivery to leaves, while soil amendment may be more appropriate for long-term effects on nutrient availability. More research is required to fully comprehend the effects of nanoparticle use and develop safe and effective applications. The timing of nano silica application can also influence its impact on crops. Early nano silica application can stimulate early root growth, resulting in more extensive and robust root systems. This improved root development allows seedlings to access nutrients and water more efficiently. Application of nano-silica during late growth stages can improve drought tolerance even further, allowing plants to complete their life cycle even in difficult dry conditions. It can help enhance harvest quality by promoting uniform ripening and mitigating the effects of stressors on grain quality.

Maize is one of the most widely grown cereal crops globally, with a high level of production and consumption. It provides a significant source of calories for millions of people. Maize is an important crop for addressing food security and nutritional needs around the world because of its adaptability, versatility, and economic importance. Its importance in global agriculture and trade is highlighted by its role in human and animal diets and various industrial applications. Maize is vulnerable to a variety of abiotic stresses, including drought, heat, and nutrient imbalances. Nano silica can improve the plant's tolerance to these stresses. It acts as a protective barrier against water loss, reduces oxidative stress, and aids in the maintenance of cell membrane integrity, improving maize's resistance to adverse environmental conditions. Research [10] shows that nano-silica can activate plant defense mechanisms against fungal and insect pests, potentially reducing reliance on harmful chemical pesticides. Nano-silica has the ability to bind and transport essential nutrients such as phosphorus and nitrogen within the maize plant, making them more available for growth and development. This has the potential to reduce fertilizer requirements as well as environmental impact. We focus on examining the effect of nano-silica on maize growth, physiological properties and yield. The application schedule of nutrients is also an important factor that ensures available nutrient demand during critical periods and maximum nutrient uptake rates in corn occurred between the 8-leaf to tassel emerging stage and again from silking to the dent stage. Therefore, the present study aims to investigate growth, physiological responses, yield components and yield of maize subjected to soil, foliar or both applications of nano silica at two different growth stages.

2. Experimental Procedure

Experimental treatments and growth condition:
The experiment took place from November 2021 to April 2022 at the Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi, Rajshahi-6205, Bangladesh, during the Rabi season. Geographically, the experimental field was located between 24°17′-24°31′N latitude and 88°28′ to 88°43′E longitude, with a height of 20m above sea level and belonged to Agro-Ecological Zone 11. Hybrid maize variety ACI-3110 was used in the experiment. The experiment includes two nano-silica application periods: 6-8 leaves stage or vegetative growth stage (V) and tasseling or reproductive growth stage (R), as well as four nano-silica application methods: soil application (SA), foliar application (FA), soil application + foliar application (SA+FA), and control or no silica application, CK. All (8) treatments were replicated three times and organized in a Randomized Complete Block Design (RCBD). Each unit plot occupied an area of 16m2 (4m × 4m) and the total unit plots were 24.

Preparation of spray materials: Silicon nanopowder (<100 nm particle size (TEM), ≥98% trace metals basis) was brought from Sigma-Aldrich and was used for this experiment. Silicon nano powder was measured as equivalent to 15 kg ha-1 for each experimental plot. 500ml of distilled water was stirred gently with a magnetic stirrer to prepare the spray solution. In the case of foliar application, nano-silica was sprayed uniformly so that all leaves could be sprayed homogeneously. A corresponding amount of silica nanopowder was applied with irrigation water in case of soil application.

Standard agronomic practices for hybrid maize cultivation were followed. The crop was fertilized with Urea, TSP, MoP, gypsum, and boric acid, which provided nitrogen, phosphorus, potassium, sulfur, and boron at rates of 540, 240, 240, 240, 15, and 5 kg ha-1. The first application included half of the urea and all fertilizers. The leftover urea was divided and applied at 30 and 60 (DAS).

Before harvest, five randomly selected plants per plot were uprooted to measure growth parameters (plant height, leaf area, total dry matter, crop growth rate), physiological parameters (relative water content, canopy cover, chlorophyll content), and yield-contributing traits (cob length, grains per cob, 1000-grain weight, grain yield, stover yield, biological yield, harvest index).
Experimental crops were harvested by plot on 10 April 2017. Before harvest, 2m² plant samples were randomly uprooted for data recording. Harvested crops were bundled, tagged, and taken to a clean threshing floor.

Measurement of relative water content (RWC)
Relative water content (RWC) was assessed using a fully expanded leaf following these procedures. [11]

$$RWC\ (\%) = \left\{\frac{(\text{fresh weight} - \text{dry weight})}{(turgid\ weight - dry\ weight)}\right\} * 100 \quad (1)$$

Measurement of canopy cover (%)

To determine canopy efficiency using photoshop software, images of leaf shades were picked using a digital camera. The image files were saved in computer hard drive and opened with Adobe Photoshop CS_3 software and data were recorded after following steps

1) Lighting and the shaded area of the Photoshop worksheet were cropped using 'Crop tool'.
2) The areas of the shades were selected via 'Magic wand tool'.
3) Pixels where picture area and shade were recorded and canopy cover was calculated using the following formula- (Figure.1)

$$\text{Canopy cover } (\%) = \left(\frac{\text{pixels of shaded area}}{\text{pixels of whole area}}\right) * 100 \qquad (2)$$

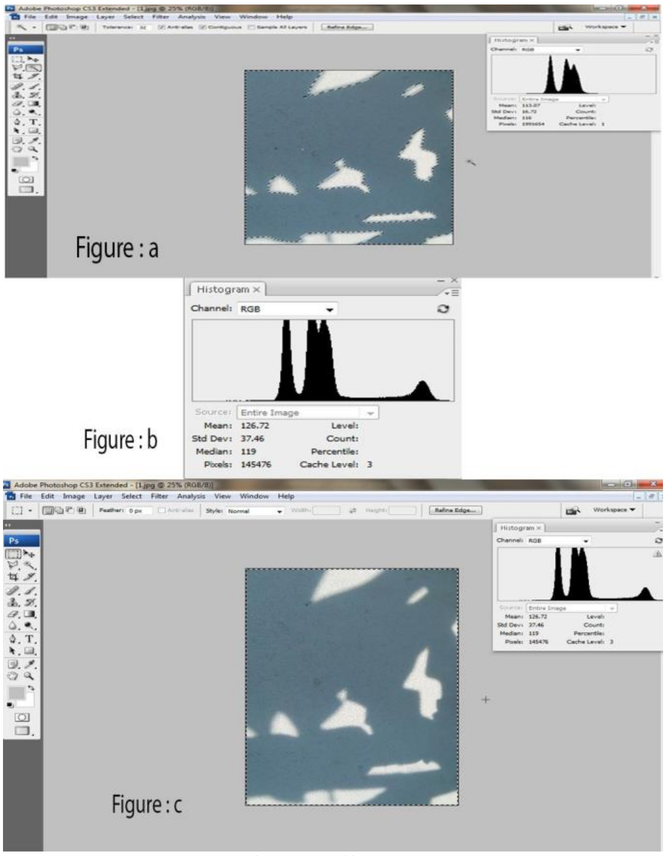

Figure 1. (a) Measurement of canopy efficiency (%) using Adobe Photoshop CS_3. (b) Selection of shaded pixels using 'Magic wand tool' Finding pixel value of shades. (c) Selection and pixel count from the total area.

Canopy Determination of leaf chlorophyll content (ChN_{RGB})Digital image analysis based on the red, green and blue (RGB) color code model was used to determine leaf chlorophyll content [12]. Images of the leaf samples were scanned using HP Scanjet G2410 (Figure 2a). Scanned images were then opened with Microsoft Paint software. To measure leaf greenness, RGB Picker software was used finally chlorophyll content (ChN_{RGB}) was calculated using the following formula as described in [12]. (Figure.2)

$$ChN_{RGB} = G - {}^{R}/_{2} - {}^{B}/_{2} \qquad (3)$$

Figure 2: (a) Image of scanned leaf. (b) Measurement of the composition of red, blue and green colors using RGB color finder.

Statistical analysis

Data were analyzed using ANOVA, and mean differences were determined with DMRT, utilizing the MSTAT-C statistical software package [13].

3. Results and Discussion

Plant growth parameters

Plant height: Plant height of maize plants for nano silica application at different growth stages (early and late) was measured on 60, 90, 120, and days after sowing (DAS) and is shown in Table 1. At 30 DAS, the plant height did not differ significantly between early and late nano silica application, but it was influenced considerably at 60, 90, and 120 DAS (Table 1). Because the first application of nano silica was made at 45 DAS, there was no discernible difference in plant height at 30 DAS. However, after being treated with nano Si, maize plants showed vigorous growth that was sustained until maturity (Table1). Plant height was 125.62, 216.25 and 227.25 cm for early application of nano silica at 60, 90 and 120 DAS, respectively. For the late application of nano-silica, the corresponding plant heights were 124.78, 208.38, 221.41 and 231.53 cm. Previous research [14], [15] claims that silica has a progressive influence on leaf expansion and plant growth. Silica is an important component of plant cell walls. Silica can be used to strengthen plant cell walls, making them more rigid and providing structural support. This is especially true during the vegetative growth stage, when plants actively produce new cells and expand in size. Enhanced cell wall strength can help plants withstand mechanical stress, such as wind or heavy rain, which is especially important during vegetative growth when the plant is rapidly growing.

During our experiment, maize plants treated with nano Si at an early growth stage started rapid growth, and it was maintained up to maturity. However late application of nano Si might not work properly because all leaves were expanded when it was applied.

Considering nano Si application methods (Soil application, SA; Foliar application, FA; Soil + Foliar application, SA + FA and control or without application, CK. Progressive effects on plant height were observed at 90 and 120 DAS (Table 1).

At 90 DAS, the tallest plant (216.4cm) was measured for FA, which was identical to SA+FA and SA but significantly 5.40% higher than CK (control). At 120 DAS, the highest plant height (231.3cm) was observed for FA, which was 2.12, 3.82 and 6.74 % higher than SA, SA+FA and CK, respectively. Foliar applications of different microelements are well known for their effectiveness [16], including Si [17]. The present research also recommends foliar application of nano Si as it influences plant height significantly compared with other application methods. Plants can absorb nutrient elements rapidly if applied to the leaves. Leaves possess transcuticular pores and stomata that allow nutrient sprays to penetrate plant cells. These pores, located on both leaf surfaces and always open, are the main entry points for foliar nutrients. Stomata, predominantly found on the underside of leaves, provide another entry route when open and sprayed on [18].

Plant height was not statistically significant due to interaction between different application periods and application methods (Table 1). At 60 DAS, the highest plant height (128.21cm) was observed for the interaction of L and SAFA and the lowest plant height (119.31cm) was observed for the interaction of L and CK. At 90 DAS, the highest plant height (223.33cm) was found for the interaction of E and FA and the lowest plant height (203.77cm) was observed for the interaction of L and CK. At 120 DAS, the highest plant height (236.0 cm) was observed for the interaction of E and FA and the lowest plant height (216.15cm) was noticed for the interaction of L and CK. The above results show that early application of nano Si is more effective for maximizing plant height if applied through foliar spray. Several previous reports [14], [19] also claimed similar observations for different crops.

Leaf area (LA)

The total leaf area (cm^2) of maize plants were measured on 30, 60 and 90 days after sowing (DAS) are presented in Table 1. The total leaf area (cm^2) did not differ significantly due to early or late application of nano Si at 30 and 90 DAS but was significantly influenced at 60 DAS (Table1). Total leaf area was found 269.15, 3149.09 and 11037.61cm^2 for early application of nano Si at 30, 60 and 90 DAS respectively. For late application of nano Si, the corresponding values were 261.26, 3121.87 and 10496.69cm^2.

Considering nano Si application methods, no remarkable difference in total leaf area was observed at 30 and 60 DAS. Foliar application of nano Si showed progressive effects in total leaf area at 90 DAS (Table1). At 90 DAS, the highest leaf area (11380cm^2) was measured for FA which was 3.93, 7.97 and 11.57 % higher than SA, SA+FA and CK, respectively. The total leaf area (cm^2) was not significantly influenced by the interaction between different application periods and application methods (Table1). At 30 DAS, the highest leaf area (275.00cm^2) was achieved by the interaction of E and FA and the lowest leaf area (255.87cm^2) was from the interaction of L and CK. At 60 DAS, the highest leaf area (3232.57cm^2) was observed for the interaction of L and FA and the lowest LA (3012.15 cm^2) was observed for the interaction of L and CK. At 90 DAS, the highest LA (11923.55cm^2) was recorded for the interaction of E and FA and the lowest leaf area (10198.38cm^2) was recorded for the interaction of E and CK.

Our observation found that the leaf area of the maize plant increased significantly with the early application of nano Si. Silicon is well known to increase leaf area, supporting leaf growth and expansion [20]. Expanded leaves are responsible for light interception, leaf photosynthesis and crop growth and development [21]. Nutrient availability is also essential for leaf growth and expansion [22]. Foliar application of Si is absorbed quickly, making it available to plants to support higher leaf area as described by [23].

Total dry matter production (TDM)

Total dry matter (TDM) differed marginally due to early or late application of nano Si at 30 and 60 DAS, but significantly at 90, 120 and 140 DAS (Table1). After the application of nano Si at 30 DAS, maize plants started to grow rapidly and were continuously maintained up to the end. Total dry matter (TDM) was found 123.88, 260.88, and 337.69gm^{-2} for early application of nano Si at 90, 120 and 140 DAS, respectively and 114.08, 252.44 and 316.44gm^{-2} total dry matters was recorded for late application of nano Si at 90, 120 and 140 DAS, respectively.

Results revealed that total dry matter production increased progressively with the advancement of time. Considering nano Si application methods, no remarkable difference in total dry matter (TDM) was observed at 30 and 60 DAS. Foliar application of nano Si showed progressive effects on TDM at 90 to 140 DAS (Table 1). At 90DAS, the highest total dry matter (127.5gm^{-2}) was produced for FA which was 5.6, 7.87 and 16.12% higher than SA, SA+FA and CK, respectively. At 120 DAS, total dry matter (273.7gm^{-2}) was observed for FA, which was 5.96, 5.96 and 15.78 % higher than SA, SA+FA and CK, respectively. At 140 DAS, highest total dry matter (346.9gm^{-2}) was observed for FA which was 4.90, 5.02 and 15.48% higher than SA, SA+FA and CK, respectively. There are no remarkable effects observed on total dry matter (TDM) due to interaction between different application periods and application methods (Table 1).

Table 1: Effect of nano silica applied at different growth stages , application methods and their interactions on Plant height, LA, TDM and CGR

Growth stages	Plant height (cm)			Leaf area (LA) cm^2			Total Dry Matter (TDM) gm^{-2}					Crop Growth Rate (CGR) $g\ m^{-2}\ day^{-1}$			
	60 (DAS)	90 (DAS)	120 (DAS)	30 (DAS)	60 (DAS)	90 (DAS)	30 (DAS)	60 (DAS)	90 (DAS)	120 (DAS)	140 (DAS)	30-60 (DAS)	60-90 (DAS)	90-120 (DAS)	120-140 (DAS)
E	125.62a	216.25a	227.25a	269.15a	3149.09	11037.61a	2.56	22.58	123.88a	260.88a	337.69a	3.49	17.5	24.63	12.57
L	124.78b	208.38b	221.41b	261.26b	3121.87	10496.69b	2.56	21.66	114.08b	252.44b	316.44b	3.48	17.05	24.46	12.54
LS	**	**	**	**	NS	**	NS	NS	**	**	**	NS	NS	NS	NS
Application methods															
SA	123.8	213.6a	226.5b	267.55	3094.61	10540c	2.583	22.48	118.2b	258.3b	330.7b	3.55	17.06ab	24.98a	12.91
FA	126.6	216.4a	231.3a	267.43	3229.23	11380a	2.57	22.27	127.5a	273.7a	346.9a	3.51	18.76a	26.06a	13.05
SA+FA	127.2	213.9a	222.8c	269.35	3169.2	10950b	2.57	21.92	120.4b	258.3b	330.3b	3.45	17.55ab	24.58ab	12.85
CK	123.2	205.3b	216.7d	256.5	3048.87	10200d	2.508	21.68	109.8c	236.4c	300.4c	3.42	15.72b	22.56b	11.4
LS	NS	**	**	NS	NS	**	NS	NS	**	**	**	NS	**	**	NS
Interaction															
E SA	127.78	216.77	228.41	272.18	3109.38	10734.5	2.57	23.33	123.27	263	343.33	3.7	17.89	24.65	12.47
E FA	127.78	223.33	236	275	3225.89	11923.55	2.577	22.07	133.07	278.4	363.34	3.47	19.7	26.09	13.68
E FASA	126.22	218.1	227.19	272.29	3175.47	11294.01	2.553	21.77	128.4	264.43	342.58	3.42	16.74	24.5	12.68
E CK	127.12	206.81	217.3	257.13	3085.59	10198.38	2.517	21.3	110.79	237.67	301.52	3.35	15.65	23.27	11.44
L SA	119.73	210.5	224.43	262.91	3079.85	10336.94	2.597	21.63	113.1	253.6	318.12	3.39	16.22	25.3	13.35
L FA	124.99	209.47	226.61	259.87	3232.57	10845.31	2.563	22.47	121.97	268.97	330.44	3.55	17.81	26.01	12.42
L SAFA	128.21	209.77	218.45	266.4	3162.92	10605.57	2.587	22.07	112.33	252.07	318.05	3.47	18.35	24.66	13.03
LCK	119.31	203.77	216.15	255.87	3012.15	10198.95	2.5	22.07	108.9	235.13	299.18	3.49	15.78	21.85	11.36
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	4.14	1.96	1.66	6.74	3.6	4.18	1.46	3.97	6.26	3.44	3.29	4.53	7.01	5.95	17.88

In a column, figures having similar letters (s) or without letters (s) do not differ significantly. E=Early growth stage (8-10-leaves stage), L= Late growth stage (tasseling stage) SA=Soil application, FA= Foliar application SA+FA= Soil application + Foliar application, CK=control, NS= Non significant, **= Significant at 1% level of probability, CV= Co-efficient of variation, DAS= Days after sowing

From Table 1, at 30 DAS, the highest total dry matter (2.597gm^{-2}) was produced for the interaction of L and SA and the lowest total dry matter(2.50gm^{-2}) was produced for the interaction of L and CK. At 60 DAS, the highest Total dry matter (23.33gm^{-2}) was observed for the interaction of E and SA and the lowest total dry matter (21.30gm^{-2}) was observed for the interaction of E and CK. At 90 DAS, the highest total dry matter (133.07gm^{-2}) was produced for the interaction of E and FA and the lowest total dry matter (108.90gm^{-2}) was produced for the interaction of L and CK. At 120 DAS, the highest total dry matter (278.40gm^{-2}) was observed for the interaction of E and FA and the total dry matter (235.13gm^{-2}) was observed for the interaction of L and CK. At 140 DAS, the highest TDM (363.34gm^{-2}) was observed for the interaction of E and FA and the lowest total dry matter (299.18gm^{-2}) was observed for the interaction of L and CK.

Dry matter production of a crop is related to biotic and abiotic factors, including nutrient availability. Although Si is not considered as an essential nutrient element, it plays an important role in maize growth, leaf area development and ultimately higher yield [24]. During our research, maize growth was found to be highest with early application of nano Si, and it was more effective if applied through foliar spray. Similar findings were further supported by [23], [25] in corn and wheat plants.

Crop growth rate (CGR)

Crop growth rate (CGR) $gm^{-2}day^{-1}$ of maize plants for the application of nano silica at different growth stages (Early and Late) was measured on 30-60, 60-90, 90-120 and 120-140 days after sowing (DAS) are presented in Table 1. The CGR showed a non-significant effect due to early or late application of nano Si at any growth stages. Crop growth rate (CGR) was found 3.49, 17.5, 24.63and 12.57 $gm^{-2}day^{-1}$ for early application of nano Si at 30-60, 60-90, 90-120 and 120-140 DAS, respectively. For late application of nano Si, the corresponding CGR was 3.48, 17.05, 24.46 and 12.54$gm^{-2}day^{-1}$.

Considering nano Si application methods, no remarkable difference in crop growth rate was observed at 30-60, and 120-140 DAS, but it was significantly higher for foliar application at 60-90, 90-120 DAS (Table1). Results showed that at 60-90 DAS, the highest crop growth rate (18.76gm-2day^{-1}) was found for FA, which was identical to SA+FA and SA but significantly 19.33% higher than CK or without application of Si. At 90-120 DAS, the highest crop growth rate (26.06 $gm^{-2}day^{-1}$) was found for FA, which was identical to SA+FA and SA but significantly 15.51% higher than CK or without application of Si. No significant effect was found due to the interaction between different application periods and methods on Crop growth rate (CGR) (Table1). During the period of 30-60 DAS the highest crop growth rate (3.70gm^{-2} day^{-1}) was observed for the interaction of E and SA and the lowest crop growth rate (3.35gm^{-2} day^{-1}) was observed for the interaction of E and CK. At 60-90 DAS the highest CGR (19.70 gm^{-2} day^{-1}) was observed for the interaction of E and SA+FA and the lowest CGR (15.65gm^{-2} day^{-1}) was observed for the interaction of E and CK. At 90-120 DAS, the highest

CGR (26.09 gm^{-2} day^{-1}) was observed for the interaction of E and FA and the lowest CGR (21.85gm^{-2} day^{-1}) was observed for the interaction of L and CK. At 120-140 DAS, the highest CGR (13.68gm^{-2} day^{-1}) was observed for the interaction of E and FA and the lowest CGR (11.36gm^{-2} day^{-1}) was observed for the interaction of L and CK. Crop growth rate is a useful indicator for the justification of different treatments. During our findings, CGR was found to be maximum with early application of nano Si and its foliar application. Both factors are also responsible for higher plant height, leaf area and dry matter production. Total dry matter production is the key component for CGR calculation. Thus CGR increases with the increase of TDM.

Nano Si application methods have no remarkable effect on relative leaf water content at 30 and 120 DAS, but they showed a negative effect on foliar application of nano Si at 60 and 90 DAS (Table 2). At 60 DAS, the highest relative leaf water content (89.36%) was observed for CK, which decreased by 2.51, 4.70 and 5.86 % for SA, SA+FA and FA, respectively. At 90 DAS, the highest RLWC (88.46) was found in CK which decreased significantly by 1.61%, 5.47% and 6.73%for SA, SA+FA and FA, respectively.

The interaction between different application periods and application methods failed to show any significant effect on relative leaf water contents (RLWC) (Table 2). At 30 DAS, the highest relative leaf water content (91.24%) resulted from the interaction of L and CK, and the lowest relative leaf water content (86.62%) resulted from the interaction of E and SA+FA. At 60 DAS, the highest relative leaf water content (89.56%) was observed for the interaction of E and CK and the lowest relative water content (82.47%) was observed for the interaction of E and FA. At 90 DAS, the highest relative water content (89.64%) was found for the interaction of E and CK and the lowest relative leaf water content (82.47%) was found for the interaction of E and FA. At 120 DAS, the highest RLWC (85.49%) was observed for the interaction of E and CK and the lowest RLWC (79.09%) was observed for the interaction of LA and FA.

Table 2: Effect of nano silica applied at different growth stages, application methods and their interactions on RWC, CE and ChN_{RGB} of maize

Growth stages	Relative water content (RWC)%				Canopy cover (%)			Chlorophyll content (ChN_{RGB})		
	30 DAS	60 DAS	90 DAS	120 DAS	60 DAS	90DAS	120 DAS	60 DAS	90 DAS	120 DAS
E	88.39	85.70a	86.52a	82.65a	71.50a	81.2	85.02a	72.23	75.33	56.07a
L	88.89	87.17b	84.29b	81.32b	68.37b	80.25	81.25b	72.08	75.53	54.29b
LS	NS	**	**	**	**	NS	**	NS	NS	**
Application methods										
SA	89.32	87.11b	87.034a	82.64	69.43b	79.53b	82.08b	70.35	75.08	53.72
FA	87.38	84.12c	82.51c	79.88	73.44a	84.70a	86.41a	77.12	80.13	60.27
SA+FA	86.93	85.16c	83.62c	80.88	72.13a	80.33b	84.97a	74.3	76.15	55.85
CK	90.92	89.36a	88.46a	84.54	64.76c	78.35b	79.06c	66.85	70.35	50.88
LS	NS	**	**	NS	**	**	**	NS	NS	NS
Interaction										
E SA	89.14	86.09	88.39	83.62	70.69	79.85	84.4	68.3	74.67	53.77
E FA	87.2	82.47	84.01	80.66	75.8	86.73	89.43	78.6	80.5	60.7
E FASA	86.62	84.69	84.04	80.84	74.15	80.32	87.29	74.67	76.07	59.17
E CK	90.61	89.56	89.64	85.49	65.35	77.92	78.95	67.3	70.1	50.63
L SA	89.51	88.13	85.68	81.66	68.16	79.22	79.77	72.4	75.5	53.67
L FA	87.55	85.76	81.02	79.09	71.07	82.68	83.39	75.6	79.77	59.83
L SAFA	87.25	85.63	83.2	80.92	70.1	80.35	82.66	73.93	76.23	52.53
L CK	91.24	89.16	87.27	83.6	64.17	78.77	79.16	66.4	70.6	51.13
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	1.93	2.4	2.21	3.61	5.46	4.93	3.61	4.84	5.06	6.1

In a column, figures having similar letters (s) or without letters (s) do not differ significantly; .E=Early growth stage (8-10-leaves stage), L= Late growth stage (tasseling stage) SA=Soil application, FA= Foliar application SA+FA= Soil application + Foliar application, CK=control, NS= Non significant, **= Significant at 1% level of probability, CV= Co-efficient of variation, DAS= Days after sowing.

Although most of the previous growth parameters showed progressive influence for early application of nano Si and foliar spray, some negative correlations were observed in RLWC. Relative leaf water content is a useful parameter indicating leaf moisture contents; it has a negative correlation with leaf expansion [26]. During our observation, both early application of nano Si and foliar spray showed progressive influence in developing leaf area. Expanded leaves are responsible for higher transpiration rate [27]. This might be the reason for reducing RLWC in maize leaf treated with early application of nano Si and foliar spray.

Canopy cover (%)

Results showed that the canopy cover (%) was not significantly affected due to early and late application of nano Si at 90 DAS, but it was significantly influenced at 60 and 120 DAS (Table 2). Canopy efficiency was 71.50 and 85.02% for the early application of nano Si at 60 and 120 DAS, respectively and 68.37 and 81.25% for the late application of nano Si at 60 and 120 DAS. In view of nano Si application methods, foliar application of nano Si showed progressive effects on canopy efficiency (%) at 60, 90 and 120 DAS (Table 2). At 60 DAS, the highest canopy efficiency (73.44%) was found for FA, which was 1.81, 5.78 and 13.40% higher than SA, SA+FA and CK, respectively. At 90

DAS, the highest canopy efficiency (84.70%) was observed for FA, which was 5.44, 6.50 and 8.10 % higher than SA, SA+FA and CK, respectively. At 120DAS, the highest canopy efficiency (86.41%) was noticed for FA, which was 1.69, 5.27 and 9.3% higher than SA, SA+FA and CK, respectively. Canopy efficiency was not statistically significant due to interaction between different application periods and application methods (Table 4). At 60 DAS, the highest canopy efficiency (75.80 %) was recorded for the interaction of E and FA and the lowest canopy efficiency (64.17%) was recorded for the interaction of L and CK. At 90 DAS, the highest canopy efficiency (86.73 %) was found for the interaction of E and FA and the lowest Canopy efficiency (77.92 %) was found for the interaction of E and CK. At 120 DAS, the highest canopy efficiency (89.43%) was observed for the interaction of E and FA and the lowest canopy efficiency (78.95%) was observed for the interaction of E and CK.

Canopy efficiency is a very important parameter closely related to leaf photosynthesis, weed suppression and crop growth. A higher leaf area is necessary to maximize canopy efficiency [28]. The Influence of nano Si on leaf development and expansion would be the reason for maximizing canopy efficiency of maize treated with early application of nano Si and foliar spray.

Chlorophyll content (ChN_{RGB})

Chlorophyll content (ChN_{RGB}) in maize leaves for the application of nano silica at different growth stages (Early and Late) were measured on 60, 90 and 120 days after sowing (DAS) (Table 2). The Chlorophyll content did not differ significantly due to early and late application of nano Si at 60 and 90 DAS but it was significantly influenced at 120 DAS (Table 2). Chlorophyll content was found 56.07 and 54.29 for early and late application, respectively for nano Si at 120 DAS. Considering nano Si application methods no remarkable difference in chlorophyll content was observed at all observations (60, 90 and 120 DAS). At 60 DAS, the highest chlorophyll content (77.12) was measured for FA and the lowest chlorophyll content (66.85) was measured for CK. At 90 DAS, the highest value (80.13) was observed for FA and the lowest value (70.35) was observed for the CK. At 120 DAS, the highest chlorophyll content (60.27) was obtained from FA and the lowest chlorophyll content (50.88) was obtained for CK. The interaction effect of different application periods and application methods of nano Si was not statistically significant in respect to chlorophyll content (Table 4). At 60 DAS, the highest chlorophyll content (78.6) was obtained from the interaction of E and FA and the lowest (66.40) was in the interaction of L and CK. At 90 DAS, the highest chlorophyll content (80.50) was observed for the interaction of E and FA and the lowest chlorophyll content (70.10) was observed for the interaction of E and CK. At 120 DAS, the highest chlorophyll content (60.70) was observed for the interaction of E and FA and the lowest chlorophyll content (50.63) was observed for the interaction of E and CK. The chlorophyll content is an important physiological parameter that increases the photosynthesis rate and thus, crop growth and development [29]. During our observation, Si was found to be less effective for chlorophyll contents in maize leaves. Silicon Is Related to Increase chlorophyll content [30]

Yield components and yield of maize

Cob Length

Cob length of maize for the application of nano silica at different growth stages (Early and Late) are presented in Table 3. Cob length did not differ significantly due to early or late application of nano Si and the highest value (28.27cm) was produced for early application of nano Si and the lowest (27.05 cm) was for late application. Nano Si application methods remarkably affected maize cob length, especially for foliar application (Table 3). The highest cob length (29.10 cm) was observed for FA, which was significantly 3.81, 6.08 and 11.62% higher than SA+FA, SA and CK, respectively. Cob length was not statistically significant due to the interaction between different application periods and application methods (Table 6). However, the highest cob length (29.96cm) was observed for the interaction of E and FA and the lowest value (25.78cm) was in the interaction of L and CK.

Number of grains per cob

Applying nano silica at different growth stages (Early and Late) significantly affected the number of grains per cob (Table 3). The Maximum value was found (553.09) for early application and the minimum value (518.43) for late application of nano Si. Considering the number of grains per cob, nano Si application was influenced significantly (Table 3). The highest number of grains per cob (562.1) was observed for FA, which was 4.02, 4.20 and 12.17% higher than SA, SA+FA and CK, respectively. The number of grains per cob was statistically significant due to interaction between different application periods and methods (Table 3). The highest number of grains per cob (582.5) was obtained from the interaction of E and FA and the lowest number of grains per cob (496.2) was found for the interaction of L and CK.

1000 Grain Weight

There was a significant effect on the 1000-grain weight due to early or late application of nano Si (Table 3). Maximum 1000 grain weight (288.55gm) was found for early application and minimum value (283.74gm) was found for late application of nano Si. According to all nano Si application methods, signification variation was observed in 1000 grain weights (Table 3). The highest 1000 grain weight (296.2gm) was observed for FA, which was 2.49, 5.60 and 6.20% higher than SA+FA, SA and CK, respectively. There was no remarkable effect on 1000 grain weight due to the interaction between different application periods and application methods (Table 6). However, numerically the highest 1000-grain weight (301.20gm) was found in the interaction of E and FA and the lowest value (278.77gm) was obtained for the interaction of E and CK.

Grain yield

The grain yield did not differ significantly due to the early and late application of nano Si (Table 3). Grain yield was found to be 6.82t ha^{-1} for the early application of nano Si and

6.48t ha^{-1} for the late application of nano Si. A significant effect was seen with respect to grain yield due to being affected by nano Si application methods. The highest grain yield (6.91t ha^{-1}) was observed for FA, which was significantly 2.83, 4.22 and 9% higher than SA+FA, SA and CK, respectively (Table 3). The overall object of the experiment was to develop a sustainable technique to predict maize grain yield. Previous research [31], [32], [33] reported increased grain yield for the application of Si. Grain yield was significantly influenced by the interaction between different application periods and application methods (Table 3). The highest grain yield (7.24t ha^{-1}) was observed for the interaction of E and FA and the lowest grain yield (6.33t ha^{-1}) was observed for the interaction of E and CK.

Table 3. Effect of nano silica applied at different growth stages , application methods and their interactions on yield components and yield of maize

Growth stages	Cob length (cm)	No. of grains cob^{-1}	1000 grain weight (g)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
E	28.27	553.09	288.55a	6.82	8.92	15.73a	43.32
L	27.05	518.43	283.74b	6.48	8.16	14.64b	44.28
LS	NS	NS	**	NS	NS	**	NS
Application methods							
SA	27.43c	540.4b	280.5b	6.63b	8.5	15.13	43.85ab
FA	29.10a	562.1a	296.2a	6.91a	8.66	15.57	44.39ab
SA+FA	28.03b	539.4b	289.0ab	6.72b	8.64	15.36	43.40ab
CK	26.07d	501.1c	278.9b	6.34c	8.34	14.7	43.15b
LS	**	**	*	**	NS	NS	*
Interaction							
E SA	28.24	565.4ab	280.2	6.76b	8.73	15.49	43.67
E FA	29.96	582.5a	301.2	7.24a	9.21	16.45	44.01
E FASA	28.52	558.5bc	294.03	6.92b	9.31	16.24	42.63
E CK	26.36	505.9de	278.77	6.35de	8.43	14.78	42.95
L SA	26.63	515.4de	280.73	6.50cde	8.28	14.78	44.04
L FA	28.25	541.7c	291.28	6.58c	8.12	14.64	44.77
L SAFA	27.53	520.3d	284.02	6.52cd	7.97	14.49	44.97
L CK	25.78	496.2e	278.93	6.33e	8.28	14.62	43.34
LS	NS	**	NS	**	NS	NS	NS
CV%	4.45	1.72	3.36	6.18	2.49	8.05	1.47

In a column, figures having similar letters (s) or without letters (s) do not differ significantly. E=Early growth stage (8-10-leaves stage), L= Late growth stage (tasselling stage) SA=Soil application, FA= Foliar application SA+FA= Soil application + Foliar application, CK=control, NS= Non significant, **= Significant at 1% level of probability, CV= Co-efficient of variation, DAS= Days after sowing.

Stover yield

The stover yield was not significant for early and late application of nano Si (Table 3). The Stover yield was found to be 8.92t ha^{-1} for the early application of nano Si; for the late application of nano Si, the stover yield was 8.16t ha^{-1}. According to all nano Si application methods, no remarkable difference in the stover yield of maize was observed (Table 3). The highest stover yield of maize (8.66t ha^{-1}) was observed for FA and the lowest stover yield (8.36t ha^{-1}) was observed for CK. Stover yield is an important parameter because it has extra value for fodder, fuel, etc. Total biomass productions are increased by the application of silica [34]. The combined effect of different application periods and methods did not significantly influence Stover yield (Table 3). The highest stover yield (9.31t ha^{-1}) was obtained from the interaction of E and SA+FA and the lowest value (7.97t ha^{-1}) was obtained from the interaction of L and SA+FA.

Biological yield

Early and late application of nano Si showed a remarkable effect on biological yield. The highest biological yield was noted 15.73t ha^{-1}, for early application of nano Si, which is 7.52 % higher than late application of nano Si (Table 3). The effect of nano Si application methods showed no remarkable difference in the biological yield of maize was observed. The highest biological yield of maize (15.57 t ha^{-1}) was produced from FA and the lowest biological yield of maize (14.70t ha^{-1}) was for CK (Table 3). The biological yield was not statistically significant due to the interaction between different application periods and application methods (Table 3). The highest biological yield (16.45t ha^{-1}) was produced for the interaction of E and FA and the lowest biological yield (14.62tha^{-1}) was produced for the interaction of E and CK.

Harvest index

The harvest index did not differ significantly due to nano Si's early and late application (Table 5). The Harvest index was found to be 43.32% for the early application of nano Si and 44.28% for the late application of nano Si. Considering nano Si application methods, a remarkable difference in harvest index was observed (Table 3). The highest harvest index (44.39%) was observed for FA which was 1.23, 2.28 and 2.87% higher than SA, SA+FA, and CK, respectively. The Harvest index was not significant due to the interaction between different application periods and application methods (Table 6). Numerically the highest harvest index (44.97%) was observed for the interaction of L and SA+FA and the lowest harvest index (42.63%) was observed for the interaction of E and SA+FA.

4. Conclusion and Future Scope

The possibility of successful growing of maize may offer a partial solution of different difficulties by bringing more area under cultivation or by increasing yield per unit area so, based on the research, maximum progressive response in maize occurred with nano Si application at early stage with foliar application methods it can be recommended that foliar application of nano Si (@15 kg/ha) at early growth stage (8-10 leaf stage) would be the best practice for maize production in experimental areas. Based on our findings, it can be stated that the present study is necessary because this research will provide an improved silica fertilization technology for maize production in Bangladesh.

Conflict of Interest

Authors have no conflict of interest on this article.

Authors' Contributions

Author-1 wrote the first draft of the manuscript, researched literature and conceived the study. Author-2 is the corresponding author, involved in protocol development, gaining ethical approval, patient recruitment, and data analysis. Both authors reviewed and edited the manuscript and approved the final version of the manuscript.

References

[1] Y. Anurag, K. Yadav, K. A. Abd-Elsalam. "Nanofertilizers: types, delivery and advantages in agricultural sustainability," *Agrochemicals*, Vol.**l2**, Issue.**2**, pp.**296-336**, **2023**. https://doi.org/10.3390/agrochemicals2020019

[2] S. Zahra, K. Khanna, N. Karimi, P. Ahmad. "Silicon and plants: current knowledge and future prospects," *Journal of Plant Growth Regulation*, Vol.**40**, pp.**906-925**, **2021**. https://doi.org/10.1007/s00344-020-10172-7

[3] A.A Ali, K.E Nasser, MS. Haythum., A B. Mohamed, M S. Tamer, "Influence of Nano-silica foliar application on growth and yield of Maize (Zea mays L.) under drought stress condition.." *Benha Journal of Applied Sciences*, Vol.**9**, Issue.**3**, pp.**1-8, 2024**. https://dx.doi.org/10.21608/bjas.2024.267108.1316

[4] A. Shoukat, P. Britta, M. S. Hossain, Z. A. Saqib, A. Nawaz, K H. Mühling, "Zinc and silicon fertilizers in conventional and nano-forms: Mitigating salinity effects in maize (Zea mays L.)," *Journal of Plant Nutrition and Soil Science,* **2024**. https://doi.org/10.1002/jpln.202300267

[5] S. Ahmed, I. Muhammadl, A. Zahoor, A. I. Muhammad, A. Arkadiusz, EL. S. Ayman, F. A Hesham, A Hossain. "Foliar application of silicon-based nanoparticles improve the adaptability of maize (Zea mays L.) in cadmium contaminated soils," *Environmental Science and Pollution Research*, Vol.**30**, Issue.**14**, pp.**41002-41013**, **2023.** https://doi.org/10.1007/s11356-023-25189-0

[6] A. Rizwan, Z. R. Muhammad, R Muhammad, U. Muhammad,A. Sidra, Hesham F. Alharby, A.B. Atif , M. .A Basmah , A Shafaqat A, "Effects of silicon nanoparticles and conventional Si amendments on growth and nutrient accumulation by maize (*Zea mays* L.) grown in saline-sodic soil," *Environmental Research*, Vol.**227**, pp.***115740***, **2023**. https://doi.org/10.1016/j.envres.2023.115740

[7] W. Islam, T Muhammad, K. Farghama, H. Zhang, H. Zhiqun, YH. C. Han, "Silicon-mediated plant defense against pathogens and insect pests," *Pesticide Biochemistry and Physiology*, Vol.**168**, pp.**104641**, **2020.** https://doi.org/10.1016/j.pestbp.2020.104641

[8] R. Putra, T. Islam, X. Cibils-Stewart, E.H. Susan. Hartley, and S.N. Johnson. "Agroecological consequences of silicon supplementation for a legume cultivation: Two-year-long field observations," Agriculture, *Ecosystems & Environment,* Vol.**365,** pp.**108893**, **2024**. https://doi.org/10.1016/j.agee.2024.108893

[9] L.Wang, N. Chuanchuan , P. Taowen, C. Kunzheng, "Role of silica nanoparticles in abiotic and biotic stress tolerance in plants: a review," *International Journal of Molecular Sciences*, Vol.**23**, Issue.**4**, pp.**1947**, **2022**. https://doi.org/10.3390/ijms23041947

[10] M. Yuvaraj, R. S. Priya, N. Jagathjothi, M. Saranya, N. Suganthi, R. Sharmila, Jaiby Cyriac, R. Anitha, K. S. Subramanian. "Silicon nanoparticles (SiNPs): Challenges and perspectives for sustainable agriculture," *Physiological and Molecular Plant Pathology,* pp.**102161**, **2023**. https://doi.org/10.1016/j.pmpp.2023.102161

[11] M.A Schonfeld, R.C Johnson, B.F Carver, D.W Mornhinweg, "Water relations in winter wheat as drought resistant indicator," *Crop Sci.*, Vol.**28**, pp.**526-531**, **1988**. https://ndlsearch.ndl.go.jp/books/R000000004-I8695121

[12] M.M. Ali, A. Al-Ani, D. Eamus, D.K.Y. Tan, "An Algorithm Based on the RGB Colour Model to Estimate Plant Chlorophyll and Nitrogen Contents," International Conference on Sustainable Environment and Agriculture (IPCBEE), *IACSIT Press, Singapore*, Vol.**57**, pp.**52-56**, **2013**. http://hdl.handle.net/10453/28424

[13] K.A. Gomez, A.A. Gomez, "Statistical Procedures for Agricultural Research. (2edn.) John Wiley and Sons. Newyork" Chikester, *Brisbane, Toronto, Singapore*. pp.**680**, **1984**. ISBN: 9780471870920, 0471870927

[14] G. Li, Z. Ma, N. Zhang, M. Li, W. Li, Z. Mo, "Foliar Application of Silica Nanoparticles Positively Influences the Early Growth Stage and Antioxidant Defense of Maize Under Low Light Stress," *Journal of Soil Science and Plant Nutrition*, pp.**1-19**, **2024**. https://doi.org/10.1007/s42729-024-01789-8

[15] Islam, Tarikul, Ben D. Moore, and Scott N. Johnson. "Silicon fertilisation affects morphological and immune defences of an insect pest and enhances plant compensatory growth." *Journal of Pest Science*. Vol. **96**, Issue **1**, pp.41-53, 2023. https://doi.org/10.1007/s10340-022-01478-4

[16] G. Asare, P. Bhatt, V. K. Avornyo, R. A. Gyamfi, "An overview of foliar application of macro and micronutrients on the yield of maize in Ghana," *Archives of Agriculture and Environmental Science*, Vol.**8**, Issue.**4,** pp.**634-638**, **2023.** https://doi.org/10.26832/24566632.2023.0804026

[17] V. Fernández, G. Eustaquio , E. Thomas, "Foliar water and solute absorption: an update." *The Plant Journal*, Vol.**105**, Issue.**4**, pp.**870-883**, **2021**. https://doi.org/10.1111/tpj.15090

[18] M.H. Alheidary, "Spraying Technology and Foliar Application Result in a Smooth Layer of the Spray: a Literature Review," *Basrah Journal of Agricultural Sciences*, Vol.**36**, Issue.**2**, pp.**334-374**, **2023**. https://doi.org/10.37077/25200860.2023.36.2.25

[19] A. B. Salih Abdel-Ati Bokila, W. Aissa Mohammed, "Irrigation Intervals and Nano-Silicon Applications Effect on Maize Growth, Yield, Yield Attributes and Chemical Composition of Grains," *Alexandria Science Exchange Journal*, Vol.**44**, Issue.**4** pp.**625-632**, **2023**. https://dx.doi.org/10.21608/asejaiqjsae.2023.326570

[20] N. Sirisuntornlak, H. Ullah, W. Sonjaroon, S. Anusontpornperm, W. Arirob, A. Datta. "Interactive effects of silicon and soil pH on growth, yield and nutrient uptake of maize," *Silicon*, Vol.**13**, Issue **2,** pp. **289-299**, **2021**. https://doi.org/10.1038/s41598-020-79723-y

[21] Y Yan, P Hou, F, Duan, "Improving photosynthesis to increase grain yield potential: an analysis of maize hybrids released in different years in China," *Photosynth Res*, Vol.**150**, pp.**295–311**, **2021**. https://doi.org/10.1007/s11120-021-00847-x

[22] X. Sun, D. Li, X. Lü, Y. Fang, Z. Ma, Z. Wang, H, Chen, "Widespread controls of leaf nutrient resorption by nutrient limitation and stoichiometry," *Functional Ecology*, Vol.**37**, Issue.**6**, pp.**1653-1662**, **2023**. https://doi.org/10.1111/1365-2435.14318

[23] G., Li, Z., Ma, N. Zhang, M. Li, W. Li, Z. Mo, "Foliar Application of Silica Nanoparticles Positively Influences the Early Growth Stage and Antioxidant Defense of Maize Under Low Light Stress," *Journal of Soil Science and Plant Nutrition*, pp.**1-19**, **2024**. https://doi.org/10.1007/s42729-024-01789-8

[24] F. Behtash, F. Mogheri, A. Aghaee, H. Seyed Hajizadeh, O. Kaya, "Role of silicon in alleviating boron toxicity and enhancing growth and physiological traits in hydroponically cultivated Zea mays var. Merit," *BMC Plant Biology*, Vol.**24,** Issue.**1**, pp.**550**, **2024**. https://doi.org/10.1186/s12870-024-05275-2

[25] A. A Ali, N.K Elgizawy, H. M Salem, M. A Bassuony, T. M Salem, "Influence of Nano-silica foliar application on growth and yield of Maize (*Zea mays* L.) under drought stress condition," *Benha Journal*

of Applied Sciences, Vol.**9,** Issue.**3**, pp.**1-8**, **2024**. https://dx.doi.org/10.21608/bjas.2024.267108.1316

[26] M. Nadal, M. J. Clemente-Moreno, A. V Perera-Castro, M. Roig-Oliver, Y. Onoda, J., Gulías, J. Flexas, "Incorporating pressure–volume traits into the leaf economics spectrum," *Ecology Letters* Vol**.26**, Issue.**4,** pp.**549-562**, **2023**. https://doi.org/10.1111/ele.14176

[27] P. A. W. Febriyani, E. Daningsih, A. N. Mardiyyaningsih, "Effect of transpiration on the monocot ornamental plants leave anatomy," pp.**598-611**, **2023**. https://doi.org/10.18006/2023.11(3).598.611

[28] Q. Song, F. Liu, H. Bu, X. G Zhu,."Quantifying contributions of different factors to canopy photosynthesis in 2 maize varieties: development of a novel 3D canopy modeling pipeline," *Plant Phenomics*, Vol.**5**, pp.**0075**, **2023**. https://doi.org/10.34133/plantphenomics.0075

[29] S. H. Shah, S. Islam, S. Alamri, Z. A. Parrey, F. Mohammad, H. M. Kalaji, "Plant growth regulators mediated changes in the growth, photosynthesis, nutrient acquisition and productivity of mustard," *Agriculture*, Vol.**13**, Issue.**3,** pp.**577,** **2023**. https://doi.org/10.3390/agriculture13030570

[30] A. Rizwan, M. Zia-ur-Rehman, M. Rizwan, M. Usman, S. Anayatullah, H. F. Alharby, S. Ali, "Effects of silicon nanoparticles and conventional Si amendments on growth and nutrient accumulation by maize (*Zea mays* L.) grown in saline-sodic soil," *Environmental Research*, Vol.**227**, pp.**115740**, **2023**. https://doi.org/10.1016/j.envres.2023.115740

[31 M. M. Miroshnychenko, Y. Y. Hladkikh, A. V. Revtye-Uvarova, O. P. Siabryk, O. M Voitovych, "Beneficial effects of silicon fertilizers on indicators of seed germination, grain yield of barley and soybean and silage corn biomass," Journal of Agricultural Sciences, *Belgrade*, Vol.**68**, Issue.**1**, pp.**43-57**, **2023**. https://doi.org/10.2298/JAS2301043M

[32] J. P. de Souza Júnior, R. de Mello Prado, J. Ferreira Diniz, V.H de Farias Guedes, J. L. F. da Silva, C. G. Roque, R. de Cássia Felix Alvarez, "Foliar application of innovative sources of silicon in soybean, cotton, and maize," *Journal of Soil Science and Plant Nutrition*, Vol.**22**, Issue.**3**, pp.**3200-3212**, **2022**. https://doi.org/10.1007/s42729-022-00878-w

[33] A. Abdelgalil, A. Mustafa, S. Ali, O. Yassin, "Effect of irrigation intervals and foliar spray of zinc and silicon treatments on maize growth and yield components of maize," *Current Chemistry Letters*, Vol.**11**, Issue.**2**, pp.**219-226**, **2022**. http://dx.doi.org/10.5267/j.ccl.2021.12.002

[34] A. Revtie-Uvarova, M. Miroshnychenko, Y. Hladkikh, O. Siabryk, O. Voitovych, "Beneficial Effects Of Silicon Fertilizers On Indicators Of Seed Germination, Biomass And Grain Yield Of Barley, Soybean And Corn," *Journal of Agricultural Sciences (Belgrade*), Vol.**68**, Issue.**1,** **2023**. https://doi.org/10.2298/JAS2301043M

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