IMPACT OF NANOSILICA ON GROWTH, PHYSIOLOGICAL PARAMETERS AND YIELD OF RICE VARIETIES CO53 AND CO54 (*ORYZA SATIVA*) UNDER DROUGHT CONDITIONS

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Abstract. The field experiment was conducted at Department of Rice, Tamil Nadu Agricultural University, Coimbatore during 2022 with the objectives to study the effect of nano-silica emulsion on growth, physiological parameters and yield of rice varieties CO53 and CO54 under drought stress. Nanosilica emulsion was prepared from pure nanosilica and it was mixed with tween 80 and water (1:3). Then solution was subjected to sonication at 50% amplification for 30 min with 10:10 plus rate. Based on the requirement of experiment, different concentrations of the nanosilica concentrations were used as foliar spray viz., 200, 400, 600, 800 and 1000 ppm under drought stress. The drought was imposed by withholding of irrigation for all treatments except T_1 (Irrigated) from 12 days before flowering and 10 days after flowering. The total period of the stress was 22 days. The irrigation was controlled by bund and the water leakage was vetoed by placing of plastic sheets. The water drained out by buffer channels in drought imposed plots. The application of 400 ppm nanosilica formulation resulted in the tallest plants and highest leaf area index, with a 16.4% increase over the control, while the CO54 variety showed the most response with a maximum increase of 18.8% in plant height and 17.9% in leaf area index under drought stress. The application of nanosilica as foliar spray at 50% flowering stage (mid of the drought period). The application of 400 ppm nanosilica formulation expressed more response in morphological (17-21%), physiological (22-35%) and yield parameters (16-30%) in CO53 and CO 54 varieties over control under drought stress. The application of nanosilica @ 400 ppm as foliar spray at 50% flowering stage is highly suitable to mitigate the drought stress in rice.
Keywords: *nanosilica, flag leaf angle, gas exchange parameters, silicon bodies, yield, rice.*

Introduction

Rice (*Oriza sativa* L.) is considered as one of the most staple food crops to the world`s population. It is grown under irrigated ecosystems and some parts of India and Tamil Nadu cultivated under rain fed ecosystems in some part of India also. Drought is the major limiting factor for rice production (Nelson et al., 2014). Therefore, enhancing rice yield amid climate change and water limitation is the first approach for enhancing rice production to meet out the food demand in future, expected from the probable increasing in world population. Plants uptake in the form of silicic acid ($Si(OH)_4$) (Ma et al., 2006). Richmond (2003) reported that on a dry weight basis, silicon deposition in plants ranges

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from 0.1 to 10%. Based on the concentration of silicon accumulation, plants are classified as silicon accumulator, intermediate and non-accumulator (Mitani and Ma, 2005). Rice plants consider as silicon accumulators because shoot dry weight contains more than 10% of silicon, sometimes comparably higher than the essential elements (Savant, 1997). In rice plants, silicon is mainly involved in the lodging resistance. Silicon is deposited in the leaf epidermis and form a double layer (Gong et al., 2003) it helps to reduce the cuticular transpiration (Zhu and Gong, 2014). Silicon deposition and cell wall modification change the turgor pressure of the guard cells, it results in a reduction in the stomatal conductance (Zhu and Gong, 2014). Silicon can induce the potassium uptake in rice plants under drought (Xu et al., 2015). Silicon can increase the nitrogen, potassium and phosphorus content in the paddy (Pati et al., 2016). Potassium involved in the stomatal opening and closing and improve the grain quality and yield in rice plants due to application of silicon (Marschner, 2012). Under drought conditions, silicon could increase the photochemical efficiency (*Fv/Fm*) and quantum efficiency (Zhang et al., 2018).

Silicon dioxide is mostly presented in sand and quartz with a crystalline tetrahedral structure. Nanosilica is amorphous in nature and vary in size from 5 to 100 nm (Imai et al., 2014). Nano fertilizer had high nutrient use efficiency (Cui et al., 2010). Seed germination increased by exogenous application of nanosilica in plants (Nair et al., 2011). Nanosilica had better results on mitigating the adverse effect of abiotic stress when compared with normal and bulk application of silicon fertilizers. The strengthening of organs involved in the transpiration process by the application of nanosilica astonishingly decreases the transpiration rate (Aqaei et al., 2020).

Potential benefits of using nanosilica in rice

Application of nanosilica as foliar spray enhanced the plant strength. Due to the increased strength, plants are also less susceptible to diseases, such as fungal infections and pest and diseases. Additionally, silicon enhances tolerance to other abiotic stresses such as drought stress, heat stress, and metal toxicity.

Why go for nano silica?

Nano silica is non-toxic and has unique properties that allow it to penetrate plants and regulate the metabolic processes like Drought tolerance: Nano silica can help rice seedlings develop stronger roots, which can improve their ability to absorb water and respond to drought. Reduced UV damage: Nano silica can help reduce the harmful effects of UV rays, such as tissue injury, low fresh weight, and decreased chlorophyll. Improved germination: Nano silica can improve germination and fresh and dry weight in tomato plants. Enhanced nutrition supply: Nano silica can help enhance the nutrition supply to plants. Improved photosynthetic efficiency: Nano silica can help improve photosynthetic efficiency (Susilo Sudarman et al., 2024). Nano silica is also considered a promising tool for improving global food security because it has several advantages over conventional products, including lower eco-toxicity, reduced input, and enhanced efficacy (Susilo Sudarman et al., 2024). Based on the aforesaid reasons, in this present study framed with the objectives of enhancing the drought tolerant capacity in rice through foliar application of different concentrations of nanosilica.

Hence, with this background, the present study has been proposed with the following three objectives chosen to validate the aim of this study to understand and analyze the flag leaf angle, gas exchange parameters, silicon bodies and yield changes under

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drought in rice varieties and also to study the amelioration response of drought stress by the foliar application of nanosilica.

Materials and methods

The field investigation was conducted at Rice department, TNAU, Coimbatore. Geographically, the experimental site was situated in the zone of western agro-climatic of Tamil Nadu at an altitude of 426.72 m above mean sea level with 11° N latitude and 77° E longitude. The total duration of the experiment was five months from January to May, 2021-2022. During the experiment period, the average of maximum and minimum temperature was 32.2°C and 22.6°C, respectively. The total amount of rainfall received during the crop period (2021-2022) was 71.3 mm. However, there is no rain fall received at the time of stress imposition and foliar application of nanosilica. The weather parameters data was collected from the ACRC, TNAU, Coimbatore. The two rice varieties of CO53 and CO54 having short duration were collected from the Rice department, TNAU, Coimbatore. The rice variety CO53 is drought tolerant released during 2020 and CO 54 is drought sensitive released during 2021 from the Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. Nanosilica (SiO_2) materials were prepared and collected from the Nano science and Technology Department, TNAU, Coimbatore (*Table 1*).

Preparation of nanosilica formulation

Nanosilica emulsion was prepared from pure nanosilica and it was mixed with tween 80 and water (1:3). Then solution was subjected to sonication at 50% amplification for 30 min with 10:10 plus rate. Solutions were well homogenized. Based on the requirement ofexperiment different concentration *viz*., 200, 400, 600, 800 and 1000 ppm of nanosilica has been prepared and used for this field study as foliar spray.

Step 1. Mixing of nanosilica with tween 80+ water (1:3 ratio)

Step 2. Sonication for 30 min

Step 3. Collect the nanosilica formulation from sonicator for foliar spray

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***Table 1.** Characters of varieties*

Variety	Parentage	Duration (days)
CO 53	PKM(R) x Norungan	115-120
CO 54	CB04110 x CB05501	115-120

The drought was imposed by withholding of irrigation for all treatments except T_1 (Irrigated) from 12 days before flowering and 10 days after flowering. The total period of the stress was 22 days. The irrigation was controlled by bund and the water leakage was vetoed by placing of plastic sheets. The water drained out by buffer channels in drought imposed plots. The application of nanosilica as foliar spray at 50% flowering stage (mid of the drought period) (*Fig. 1*). Totally seven treatments were chosen for this experiment viz., T_1 – Irrigated, T_2 – Drought, T_3 – Drought + Nanosilica (200 ppm), T_4 – Drought + Nanosilica (400 ppm), T_5 – Drought + Nanosilica (600 ppm), T_6 – Drought + Nanosilica (800 ppm) and T_7 – Drought + Nanosilica (1000 ppm).

Observations recorded

Plant sampling

The growth anatomical, physiological, biochemical and yield parameters were recorded in each treatment with three plants per replications per treatments were collected atseven days after application of nanosilica in 50% flowering stage and physiological maturity stage for measuring all the observation.

Growth attributes

Plant height (cm)

Three randomly selected plants from each plots were selected for plant height measurement. Plant height was measured from the bottom of the stem to tip of the panicle foreach treatment and expressed in cm.

Leaf area index

Leaf area index of the plant for each treatment was calculated by the method of Cock et al. (1976).

$$\text{LAI} = \text{Total Leaf Area of the plant } (\text{cm}^2) / \text{ spacing } (\text{cm}^2)$$

Flag leaf angle

The flag leaf angle was measured at seven days after the application of nanosilica by using the leaf protractor. It indicates the erectness of the leaf and expressed in ° (degrees).

Leaf surface characters

Silicon bodies of two rice varieties were viewed and measured under the scanning electron microscope (SEM) at seven days after foliar applicationof nanosilica.

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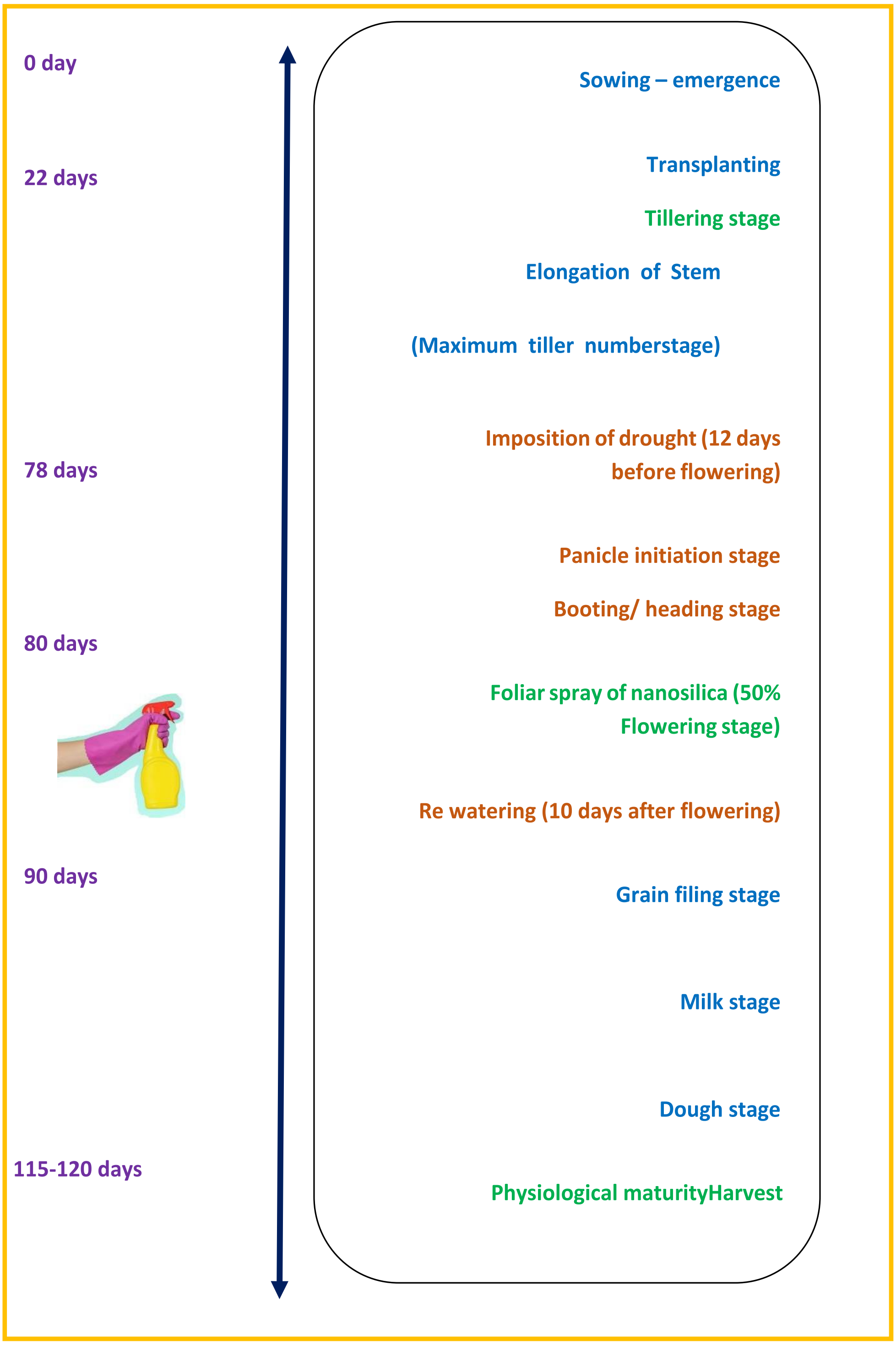

Figure 1. *Flow chart for drought imposing period in rice*

Chlorophyll index (SPAD value)

The chlorophyll index was measured by using SPAD- 502 (Minolta, Japan) in fully expanded physiologically active flag leaf. SPAD reading or SAPD value is transmittance ratioof red light at 650 nm and infra-red light at 940 nm. This SPAD value indirectly considered aschlorophyll content.

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Photosynthetic parameters

Gas exchange parameter like photosynthetic rate (*P*n) (µmol CO_2 m^{-2} s^{-1}), rate of transpiration (*E*) (m mol H_2O m^{-2}), stomatal conductance (gs) (mol H_2O m^{-2} s^{-1}) were observedby using a PPS (portable photosynthetic system) instrument (LI-6400; LI-COR Inc. Lincohn,Nebraska, USA). These parameters were measured at the light intensity of 1500 µmolm^{-2} s^{-1} PAR, leaf temperature 30°C and CO_2 concentration matched with ambient CO_2 concentration.Observation was taken between 9.00 am to 12.00 pm in fully expanded physiologically activeflag leaf with three replication for each plot.

Chlorophyll fluorescence

Chlorophyll fluorescence meter (Model:opti-Sciences OS1p) was used for measuring the chlorophyll fluorescence. Specially made leaf clips are used for dark adoptions. The leaveswere dark adopted for 30 min. After that slit is opened for the measurement of fluorescence. Adoption of light gives electron transport rate (ETR) and Y (II). Instrument automatically calculated the important fluorescence parameters such as initial fluorescence (F_O), Maximumfluorescence (*Fm*), Variable fluorescence (*Fv*) and *Fv/Fm* ratio.

Yield parameters

The yield and yield characters were measured during harvest stage in all the varieties and treatments.

Statistical analysis

The data were collected and subjected to statistical examination in factorial randomizedblock design (FRBD) (Gomez et al., 1984).

Results and discussion

Plant height

The results on plant height are illustrated in *Figure 1*. The observation on plant height showed an increasing trend in control and declined trend in drought and silica nano formulation applied plants. Between the two varieties, CO53 recorded maximum plant height of 125.4 cm than the CO54 (112.1 cm) under control (Irrigated). A significant variation could also be observed between drought alone and drought with nanosilica applied plants. Among the different nanosilica treatments, T_4 (Drought + 400 ppm) registered tallest plant of about 94.1 cm and 117.0 cm in CO54 and CO53 with lesser reduction over drought alone treatment. Current study shows maximum height reduction of 29.3%in CO54 followed by CO53 (18.2%). These results revealed that, CO53 had comparatively more resistance than CO54. Application of silica nanoformulations increases the plant heightby 14.0% to 18.8% (*Fig. 2*). Rice crop is more sensitive to water deficit condition particularlyin reproductive stage (Agarwal et al., 2016). Plant height an indirect trait determines the yield and directly influenced by various environmental factors (Moldenhauer and Nathan, 2003). Cyclin-dependent kinase A (CDKAs) an important regulatory compound in cell cycle and decreased activity of CDKAs observed under drought, thereby reduce the cell division (Schuppler et al., 1998). In present study

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shows a 26.5% reduction of plant height observed. These results are agreement with Ahmadikhah and Marufinia (2016). Application of silicon increases the plant height it may be due to silicon involved in the cell division or cell elongation. Lavinsky et al. (2016) who reported that silicon is responsible for erectness of leaves thereby receiving the more sunlight by all the leaves to increases the photosynthesis andplant height. This evidence in agreement with this present study noticed that, silica in the form of nanoformulations improve the plant height. Same kind of results observed by Gong et al. 2005 in wheat, Ding et al. (2007) insisted that silicon improve the plant height in sugarcane under drought condition.

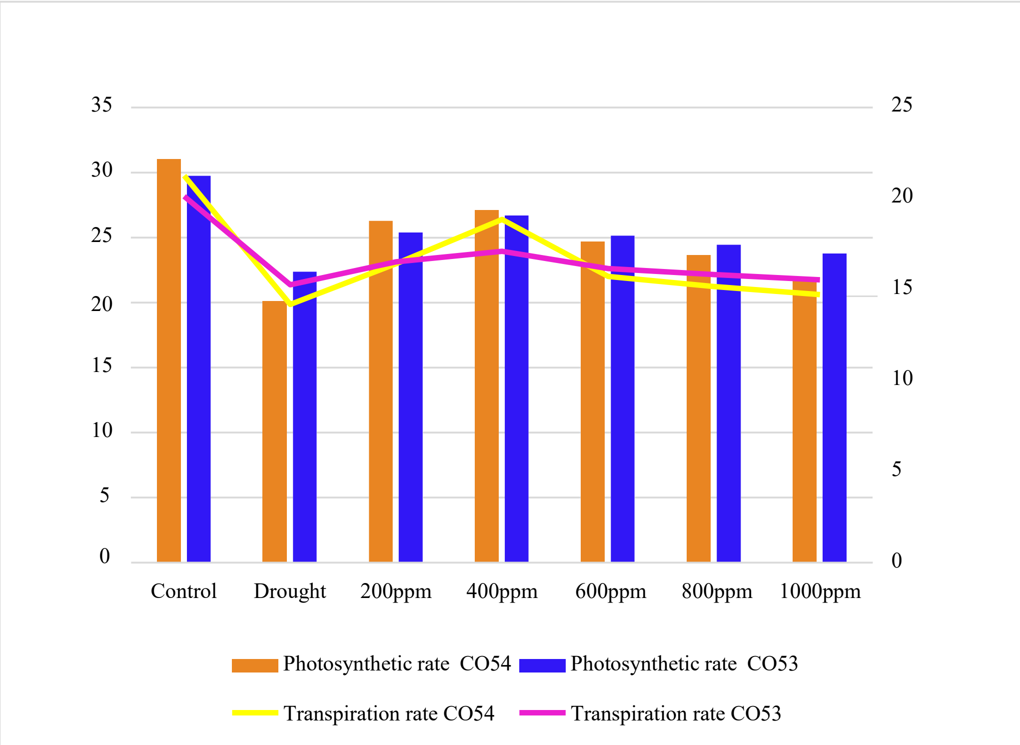

Figure 2. *Effect of silica nanoformulations on photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) and transpiration rate (m mol H_2O m^{-2} s^{-1}) in rice under drought condition*

Leaf area index

The data on leaf area index showed an increased trend in the control plants whereas declining trend was observed in the drought alone and drought with nanosilica applied plants (*Table 2*). Besides, maximum leaf area index could be recorded in the control alone plants. Between the two varieties, CO53 maintained its superiority in highest leaf area index of about 4.54 than the CO 53 (4.36) under control. A significant variation could be observed in droughtalone and drought with nanosilica applied plants. Among the different nanosilica treatments, T_4 had rank first in leaf area index of about 4.47 and 4.25 in CO53 and CO54 respectively under drought, which was significantly higher than the drought alone treated plants (CO53- 4.04; CO54-3.60), followed by T_3 (CO53-4.26; CO54-4.15) treatment. Leaf area index represent the ground area occupied by the plant and directly related with biomass production (Wang et al., 2007). Photosynthetic rate and canopy radiationinterception are passively correlated with leaf area index. Present research output

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shows, drought negatively impact on leaf area index. This evidence in agreement with the present study found that, the variety CO54 had 17.4% reduction, whereas CO53 had 11% reduction under drought. Overall drought reduction recorded about 14.25%. Application of silicon reduces the impact of drought on leaf area index. These results are agreement with Ming et al. (2012) who stated that, silicon increases the water potential of theleaf to improve the leaf surface area index. The same kind of results reported by Ahmed et al. (2011) in sorghum. Singh et al. (2005) proofed that leaf area index reduced due to drought; besides application of silicon increase the leaf area index through maintaining leaf water statusunder drought in rice.

Table 2. *Effect of silica nanoformulations on plant height (cm) and leaf area (cm^2 plant^{-1}) in rice under drought condition*

Plant height (cm)			Leaf area index	
Treatments	**CO54**	**CO53**	**CO54**	**CO53**
T1 - Control	112.1	125.4	4.36	4.54
T2 - Drought	79.2	102.6	3.60	4.04
T3 - Drought + 200 ppm	89.1	111.3	4.15	4.26
T4 - Drought + 400 ppm	94.1	117.0	4.25	4.47
T5 - Drought + 600 ppm	85.4	108.4	4.05	4.20
T6- Drought + 800 ppm	83.4	105.1	3.92	4.14
T7 - Drought + 1000 ppm	82.5	104.0	3.88	4.09
Mean	**89.4**	**110.6**	**4.03**	**4.25**
	SEd	**CD (0.05)**	**SEd**	**CD(0.05)**
V (Variety)	1.41	2.89 **	0.088	0.182*
T (Treatment)	2.63	5.41 **	0.165	0.340**
V × T	3.72	7.65	0.234	0.480
	* Significant at 5% level		** Significant at 1% level	

Flag leaf angle

The results on flag leaf angle revealed that, an increased trend was observed in control plants and declined trend in drought alone and drought with nanosilica applied plants (*Table 3*). Comparing the two varieties, CO54 had maximum flag leaf angle of 33.3° and 17.3° in CO53 under control alone treatment. Among the nanosilica treatments, a significant decreasesof flag leaf angle could also be observed in T_4 (Drought + 400 ppm) treatment of 16.0° in CO54and 10.3° in CO53 respectively, which was close to the drought alone treatment (CO54-23.3°;CO53-12.7°). Flag leaf playing a major role for providing the photosynthetic energy to the developinggrains and any effect due to abiotic stresses in flag leaf photosynthesis have a higher reductionon grain yield and productivity in rice (Huang et al., 2021). According to Moldenhauer et al. (2003) stated that, the flag leaf angle deals to the joining between the blade of the flag leaf and vertical culm. The flag is the top most leaf which is very close to the panicle and giving photosynthetic energy for better development of rice grain (Dong et al., 2018). In rice, the erectness of the leaf is mainly based on the cellular organization in the joining of lamina. Hence, the abaxial and adaxial side elongation of cell and the leaf mechanical tissue development with cell composition impact the leaf erectness and flag leaf angle positively (Zhao et al., 2013).

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Yoshida (1972) opined that, flag leaf export photoassimilates to the panicle in rice. According to Slewinski (2012) who stated that, the flag leaf length and leaf angle is affected due to drought. The application of silicon in rice had the effect of change in the flag leaf angle under drought. These evidence are in strong agreement with the present study foundthat, under drought condition, minimum flag leaf angle of 23.3° with 30% angle reduction over control were noticed in CO54 variety. However, the variety CO53 had 12.7° with 27% angle reduction under drought condition. The variety CO54 and CO53 treatedwith nanosilica had maximum of flag leaf erectness of about 10.0° to 18.0° with 9.3° to 12.0°under drought conditions respectively. These results were in evidence on the flag leafangle by the application of silica under abiotic stress condition in rice (*Fig. 3*). According to Avila et al. (2010), who opined that, application of silica influenced in the more flag leaf erectness alsoincreasing the photosynthetic efficiency with small opening the angle of flag leaf which leadsto greater capturing light energy for enhancement of photosynthesis in rice.

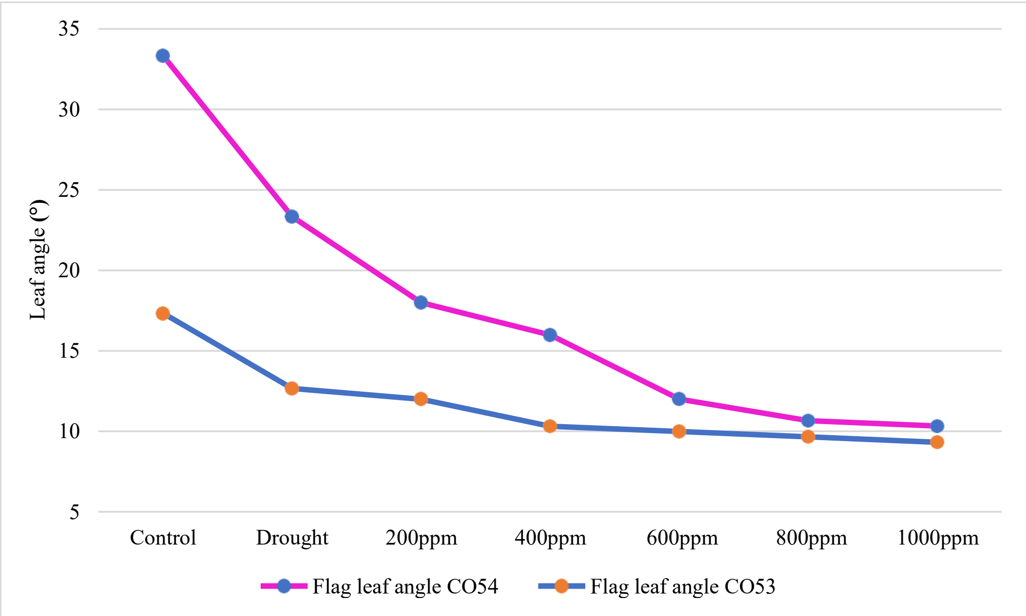

***Figure 3.** Effect of nanosilica on flag leaf angle (°) in rice under drought condition*

Chlorophyll index (SPAD)

The data on chlorophyll index of different nanosilica treatments were differed significantly and reported in *Table 3*. An increased trend was observed in control plants; besides a smaller reduction of chlorophyll index were recorded in the drought alone and drought with nanosilica applied plants. Highest chlorophyll index value of 43.9 observed in CO54 than CO53 (42.1) under control condition. Between the CO53 and CO54 varieties, CO53 had maximum chlorophyll index value of 36.7, whereas CO 54 had 35.4 under drought alone condition. Among the different nanosilica treatments, T_4 maintained its superiority in chlorophyll index value of 41.2 registered by CO54 and 40.4 by CO53 respectively, which was close to T_1 (Irrigated) and T_3 (CO53-39.7; CO54-38.8) treatments. Soil plant analysis development (SPAD) is an instrumental reading and it is used for the estimation leaf nitrogen status and indirect measurement of chlorophyll content in the leaf

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(Bojovic and Markovic, 2009). The measurement of chlorophyll index (SPAD) value determined the leaf green index and also the concentration of chlorophyll pigment present in the leaf chloroplast. The greater SPAD value indicates the greater chlorophyll concentration, which enhance the photosynthetic efficiency. According to Wood et al. (1993) and Wang et al. (2004) who proofed that, a strong positive correlation showed between the chlorophyll and nitrogen content. The results showed that, the chlorophyll index was reduced under drought condition with 13.0 to 19.2% reduction were noticed in CO54 and CO53 varieties. Among the varieties, CO 53 had minimum reduction of 13.0%, whereas CO54 had 6.2% reduction over the control. Application of 400 ppm nanosilica significant increases the chlorophyll index value of 16.2% in CO54 under drought than the drought alone. It is clearly shown CO54 had more response to nanosilica application than the CO53. In this present study, a decreasing trend of chlorophyll index was observed under drought. These results were in agreement with Monostori et al. (2016) reported that, chlorophyll index was reduced under drought in wheat. In this present study also observed that, a positive correlation between the foliar application of nanosilica and chlorophyll index. It might be due to silicon improve the activity of 'N' fixing microbes and combine effect of silicon and potassium can improve the nitrogen use efficiency (Mali and Aery, 2008). Chen et al. (2011) opined that silicon will improve the mineral nutrition absorption in plants under drought in rice. These evidence are strong agreement with Paul (2013) reported that, increased the concentration of silica will induce the synthesis of organic compounds by rice plants through enhancement of photosynthetic efficiency in rice.

Table 3. *Effect of silica nanoformulations on chlorophyll index, flag leaf angle (°) and silica bodies in rice under drought condition*

Chlorophyll index (SPAD)			Flag leaf angle (°)		Silica bodies (µm)	
Treatments	**CO54**	**CO53**	**CO54**	**CO53**	**CO54**	**CO53**
T1 - Control	43.9	42.1	33.3	17.3	13.02	12.34
T2 - Drought	35.4	36.7	23.3	12.7	13.54	14.10
T3 - Drought + 200 ppm	39.7	38.8	18.0	12.0	16.12	16.12
T4 - Drought + 400 ppm	41.2	40.4	16.0	10.3	17.08	18.70
T5 - Drought + 600 ppm	38.7	37.9	12.0	10.0	15.87	15.43
T6- Drought + 800 ppm	37.7	37.3	10.7	9.7	15.51	15.26
T7 - Drought + 1000 ppm	36.4	37.0	10.3	9.3	15.20	14.30
Mean	**39.0**	**38.6**	**17.7**	**11.6**	15.19	15.18
	SEd	**CD(0.05)**	**SEd**	**CD(0.05)**	**SEd**	**CD(0.05)**
V (Variety)	0.526	1.082	0.614	1.262**	0.249	0.511
T (Treatment)	0.985	2.024**	1.149	2.362**	0.4654	0.957**
V × T	1.393	2.863	1.625	3.340**	0.658	1.353
	* Significant at 5% level		** Significant at 1% level			

Silicon bodies length

The data (*Table 3*) represent the silicon bodies present in the leaf surface. Results revealed that nanosilica treatment had increasing trend and drought alone and control plants had declining trend. Comparing the two rice varieties, CO54 had minimum silicon body length of 13.02 µm than the CO53 (12.34 µm) under control alone condition. However, a

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considerable increment could also register in silicon body length due to drought. Maximum silica bodies length recorded in CO53 (14.10 µm) than CO54 (13.54 µm) under drought alone condition. A significant increasing trend could also be noticed in nanosilica treatment (*Fig. 4*). Among the different silica treatments, T_4 had maximum silicon bodies length of 18.70 µm than all the other treatments. In T_4 treatment, the varieties CO53 and CO54 both on par with each other. Silicon absorbed from the lateral roots and deposited in stems, lead sheath, and leaf blade in the form of silica bodies (Okuda and Takahashi, 1961). It is essential for logging resistance, then biotic and abiotic stress tolerance in rice (Yoshida et al., 1969). Under drought condition activate the silicon transporters to active adsorption of silicon. Application of silicon directly correlated with the size and number of silicon bodies in the leaf surface (Agarie et al., 1998), these results are agreement in present study. Drought condition size of the silicon bodies is increased. CO53 had maximum size increases of 14.2% than CO54 (4%) over the control (*Table 3*). Application of silicon 400 ppm of nanosilica increase the maximum percent of 32.7% of silico bodies size in CO53 than CO54 (26.14%) over the drought. Application of silicon increases increase the silicon bodied. It may be due to application of silicon deposited in the silico bodies, which increases the size (Agarie et al., 1998). Isa et al. (2010) reported that silicon may be deposited in the motor cells of leaf, it helps to maintain the water status of the leaf.

Photosynthetic rate

The results on photosynthetic rate illustrated in *Table 4*. The results showed that control plants had maximum photosynthetic rate than the drought alone and drought with nanosilica treated plants. Comparing the control and drought alone treatment, control plants had highest photosynthetic rate of 31.0 µmol CO2 m^{-2} s^{-1} registered by CO54 than CO53 (29.8 µmol CO2 m^{-2} s^{-1}). Besides in drought alone treatment, CO53 had highest photosynthetic rate of (22.4 µmol CO2 m^{-2} s^{-1}) than CO54 (20.1 µmol CO2 m^{-2} s^{-1}). Between two varieties expressed that, nanosilica treated plants had significant increases in photosynthetic rate under drought condition over the drought alone treatment. Comparing the different nanosilica treatments, T4 (Drought + 400 ppm) maintained its superiority in higher photosynthetic rate of 27.1 µmol CO2 m^{-2} s^{-1} observed in CO54 than the CO53 (26.7 µmol CO2 m^{-2} s^{-1}). Both varietiesand treatments are on par with each other. Photosynthesis is a vital process, conversion of light energy to chemical energy, 40% of atmospheric carbon are fixed into the plants. Carbon takes in the form of CO_2 modified in to hexose sugar molecule by serious biochemical reactions (Lambers et al., 2008). Photosynthesis is a process of conversion of light energy into chemical energy (Lambers et al., 2008). The rate of photosynthesis is mainly depends upon the amount of chlorophylls and other photosynthetic pigments are present in thylakoid membranes of grana.According to Parry et al. (2002) stated that, RuBisCO is the important abundant enzyme fix the atmospheric carbon di-oxide fixation in plants during the photosynthesis. This RuBisCO enzyme is highly sensitive to drought. Under drought condition, chloroplast and other cell organelles are affected due to insufficient of water content also damaging of chlorophyll molecules and photosystems which leads to decreasing of photosynthetic rate. Silicon is considered as quasi essential element for growth and development of the riceplant (Epstein and Bloom, 2005). According to Tripathi et al. (2015) reported that, application of silicon maintaining the photosynthetic rate and efficiency through stabilization of chloroplast structure; besides it increases the PS II integrity and pigment concentrationpositively in rice. This evidence is in agreement with

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the present study found that, the varietyCO53 had minimum reduction in photosynthetic rate of 18.9% under drought condition. However, the variety CO54 had maximum reduction in photosynthetic rate of 35.2% over control. In present study a significant increase of 19.0 to 34.8% could also be observed in photosynthetic rate with the application of 400 ppm of nanosilica (*Fig. 2*). These results are agreement with Shi et al. (2014), who strongly reported that, the maintenance of photosynthetic rate may be due to silica deposition which leads to reduce the production of reactive oxygen species and also decreases the degradation of chlorophyll a and chlorophyll bcontent, which leads to maintenance of photosynthetic rate in rice under drought.

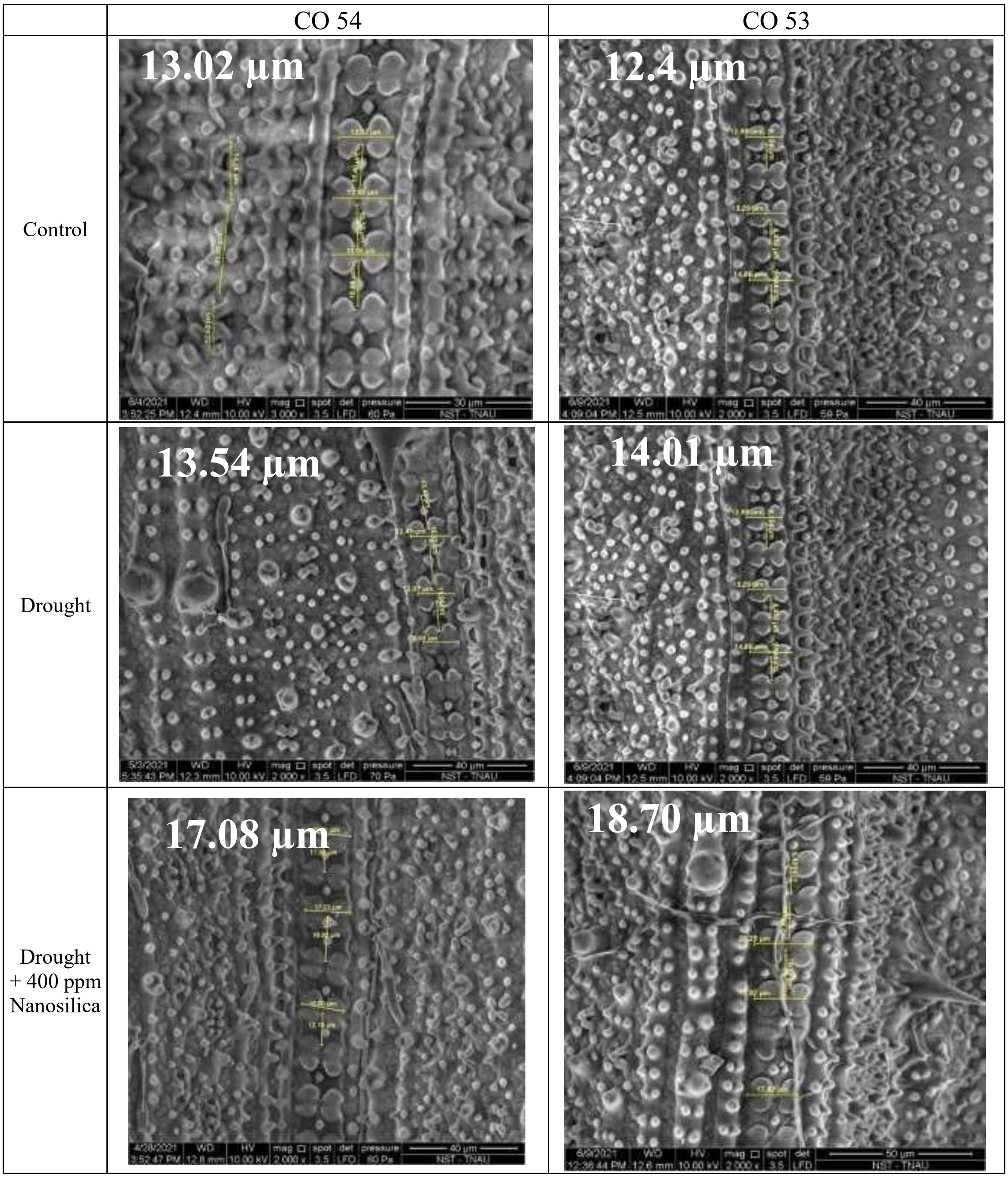

***Figure 4.** Effect of silica nanoformulations on silica bodies (µm^2) in CO54 and CO53 n rice under drought condition observed under Scanning Electron Microscope-EDAX method*

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Table 4. *Effect of silica nanoformulations on photosynthetic rate (µ mol CO_2 m^{-2} s^{-1}) and transpiration rate (m mol H_2O m^{-2} s^{-1}) inrice under drought condition*

Photosynthetic rate (µmol CO2 m^{-2} s^{-1})			Transpiration rate (mmol H2O m^{-2} s^{-1})	
Treatments	**CO54**	**CO53**	**CO54**	**CO53**
T1 - Control	31.0	29.8	21.3	20.1
T2 - Drought	20.1	22.4	14.2	15.3
T3 - Drought + 200 ppm	26.3	25.4	16.4	16.5
T4 - Drought + 400 ppm	27.1	26.7	18.9	17.1
T5 - Drought + 600 ppm	24.7	25.1	15.7	16.2
T6- Drought + 800 ppm	23.6	24.4	15.2	15.8
T7 - Drought + 1000 ppm	21.7	23.8	14.7	15.5
Mean	**24.9**	**25.4**	**16.6**	**16.7**
	SEd	**CD (0.05)**	**SEd**	**CD (0.05)**
V (Variety)	0.196	0.403*	0.200	0.412
T (Treatment)	0.367	0.755**	0.375	0.772**
V × T	0.519	1.068**	0.531	1.092**
	* Significant at 5% level		** Significant at 1% level	

Transpiration rate

The experiment results on transpiration rate exhibited in *Table 4* and similar trend were noticed as like photosynthetic rate. It shows that maximum transpiration rate of 21.3 m mol H_2O m^{-2} s^{-1} registered by CO54 than CO 53 (20.1 m mol H_2O m^{-2} s^{-1}) under controlled condition. Comparing the two varieties, CO53 had maximum transpiration rate of 15.2 m mol H_2O m^{-2} s^{-1} than the CO54 (14.2 m mol H_2O m^{-2} s^{-1}) under drought alone condition. Among the different nanosilica treatments, T_4 (Drought 400 ppm) recorded maximum transpiration rate of 18.9 m mol H_2O m^{-2} s^{-1} in CO54 over the other treatments, meanwhile the variety CO53 had 17.1 m mol H_2O m^{-2} s^{-1}. Both varieties in the T_4 treatments are on par with each other. The transpiration is an essential physiological process for maintaining the plant body temperature and also pumping the water and nutrients to the source organs for photosynthesis. According to Vandeleur et al. (2009), who reported that, drought has a negative effect on transpiration and hydraulic conductance of the leaf and roots. During transpiration water enter into roots xylem from the soil following the apoplastic pathways precise over by a hydraulic pressure gradient. Nevertheless, the reduction of transpiration rate under drought, maximum amount of the water follows the pathway of cell to cell also water flowing across the living cellular membranes (Steudle, 2000). Silicon playing a major role in transpiration. Guntzer et al. (2012) opined that, the reduction of transpiration rate from the cuticle due to higher accumulation of silicon in the culm, leaves, and hulls thus increasing drought stress tolerance in the rice. The impact of drought in reducing the rate of transpiration could be noticed in both rice varieties under drought condition. The variety CO53 had 20-24% reduction, while CO54 with 17-20% reduction under drought (*Fig. 2*). Differential nanosilica treatment responses were also observed in terms of transpiration rate under drought positively. The present study revealed that application of 400 ppm of nanosilica had better increment transpiration rate under drought over the

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other concentration of nanosilica. It was also exhibited that the slight increase in transpiration rate in response to drought with nanosilica application is a character which causes a significant entry of CO_2 for maintaining photosynthesis. These results are in strong agreement with Guerriero et al. (2016), who found that, silicon deposited in the cuticle layer for reducing the transpiration rate. Besides these results, Chen et al. (2021) strongly reported that, application of silicon could improve the root traits to enhance water uptake therefore increasing resistance to drought in rice. However, our study showed that the significant increasing in transpiration rate in rice leaves under drought by nanosilica application. According to Hottori et al. (2008), reported that the alleviation through silicon application was independent of water status of leaf.

Stomatal conductance

From the data presented in *Table 5* shows a significant variation were observed in control alone, drought alone and drought with nanosilica applied plants. An increasing trend could be observed in control plants and declined trend in drought alone and drought with nanosilica applied plants. Maximum stomatal conductance of 1.57 moles H_2O m^{-2} s^{-1} registered by CO54 than the CO53 (1.43 moles H_2O $m^{-2}s^{-1}$). A significant variation could also be noticed in increases of stomatal conductance between drought alone and drought with silica nano forulation treated plants. Among the different nanosilica treatments, T_4 (Drought + 400 ppm) registered maximum value of stomatal conductance in CO54 (1.35 moles H_2O m^{-2} s^{-1}), and CO53 (1.33 moles H_2O m^{-2} s^{-1}), which was followed by T_3 (CO54; 1.18 moles H_2O m^{-2} s^{-1}) and (CO53-1.12 moles H_2O m^{-2} s^{-1}) respectively. However, a considerable reduction could also be noticed in stomatal conductance due to drought (CO53-0.77 moles H_2O m^{-2} s^{-1}; CO54-0.85 moles H_2O m^{-2} s^{-1}). Stomatal conductance is an important physiological parameter for measuring the degree of stomatal opening. According to Jeanguenin et al. (2016) stated that, stomatal conductance can be used as a plant water status indicator. This parameter used to measure the amount of CO_2 entering and water vapor existing through the stomata. Under water deficit condition there was a decreasing conductance of the stomata could noticed by Hottori et al. (2005) and Ibrahim et al. (2018) in rice. The effect of drought in reduction of stomatal conductance could be observed from this present study in CO53 and CO54 rice varieties. The variety CO54 had higher reduction in stomatal conductance due to drought with 50.9%, while CO53 with 40.5% reduction over control. These results are in agreement with Nonami et al. (1991), who reported that, the cuticular layer plays a major role in regulation of stomata by limiting the movement of water from xylem vessels to transpiration site and rate of guard cell water loss to ambient air. In rice, silica is mostly accumulated in the leaf epidermal cells and forming cuticular silica double layer at the epidermal cell surface beneath the cuticle (Elawad et al, 1982). Our research finding exhibited that application of 400 ppm of nanosilica under drought condition had a significant increase in stomatal conductance of about 51.3 to 59.6% in CO53 and CO54 varieties. These results are in agreement with Sarkar et al. (1996), who strongly supported that, silica in combination with the stomata and cuticle, influences regulation of stomata by minimizing water condition in the cells of epidermis i.e. regulation of transport of water in the epidermal and guard cell water loss in rice. Beside these results, Maghsodi et al. (2016) in wheat, Varma et al. (2020) in sugarcane reported that, application of silicon improve the stomatal; conductance under water deficit condition.

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Table 5. *Effect of silica nanoformulations on stomatal conductance (moles H_2O m^{-2} s^{-1}) and maximum photochemical efficiency ofPS II (Fv/Fm ratio) in rice under drought condition*

Stomatal conductance (moles H2O m^{-2} s^{-1})			**Maximum photochemical efficiency of PS II (*Fv/Fm* ratio)**	
Treatments	**CO54**	**CO53**	**CO54**	**CO53**
T1 - Control	1.57	1.43	0.79	0.77
T2 - Drought	0.77	0.85	0.63	0.68
T3 - Drought + 200 ppm	1.18	1.12	0.74	0.73
T4 - Drought + 400 ppm	1.35	1.33	0.77	0.76
T5 - Drought + 600 ppm	0.91	0.99	0.70	0.72
T6- Drought + 800 ppm	0.84	0.94	0.66	0.70
T7 - Drought + 1000 ppm	0.78	0.89	0.65	0.69
Mean	**1.05**	**1.08**	**0.71**	**0.72**
	SEd	**CD (0.05)**	**SEd**	**CD (0.05)**
V (Variety)	0.018	0.038	0.005	0.011**
T (Treatment)	0.034	0.071**	0.010	0.021**
V × T	0.0491	0.101**	0.014	0.029*
	* Significant at 5% level		** Significant at 1% level	

Photosynthetic efficiency (Fv/Fm ratio)

The data (*Table 5*) represent the maximum photosynthetic efficiency. Results revealed that control alone treatment had maximum photosynthetic efficiency trend and drought alone and drought with nanosilica applied plants had minimum photosynthetic efficiency of *Fv/Fm* ratio. Comparing the two rice varieties, CO54 had maximum *Fv/Fm* ratio of 0.79 than the CO53 (0.77) under control alone condition. However, a considerable reduction was observed in *Fv/Fm* ratio due to drought. Minimum *Fv/Fm* ratio recorded in CO54 (0.63) than CO53 (0.68) under drought alone condition. A significant increasing trend could also be noticed with nanosilica treatment. Among the different silica treatments, T_4 had maximum *Fv/Fm* ratio of about 0.77 in CO54 and 0.76 in CO53. In T_4 treatment, the varieties CO53 and CO54 both on par with each other. The ratio of *Fv/Fm* is an important physiological measurement representing the maximum quantum efficiency potential of photosystem II. The approximate range of *Fv/Fm* value is 0.79 to 0.84 for many plant species; besides, the value is lesser than the approximate *Fv/Fm* values indicating plant under stress (Maxwell and Johnson, 2000). Photosystem II is an important complex in light reaction, bind with D1 and D2 proteins. D1 proteins are highly sensitive to drought (Taizs and Zeiger, 6th edition; Bukhov et al., 1998). Under drought, these was a numerous production of reactive oxygen species (ROS) in plants cell which affect the reaction centre of photosystem II (PS II) (Lu and Zhang, 1999) and directly reflected in yield loss (Li et al., 2015). In the present study exhibited a significant reduction could be observed in *Fv/Fm* ratio under drought in both varieties. The variety CO54 had maximum decreasing of *Fv/Fm* ratio of 20.1% than CO53 (11.7%) under drought condition. It proofed that, CO54 had highly susceptible to drought than CO53. Application of silicon slightly improves the photochemical efficiency of PS II under drought. Application of 400 ppm nanosilica significantly increases the photochemical efficiency in drought induced plants. CO54 had maximum

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response to nanosilica application and shows 20.5% increases in *Fv/Fm* ratio, while CO53 had 12.8% of photochemical efficiency under drought. Reduction in photosynthetic efficiency mainly due to the production of reactive oxygen species and it affects the thylakoid membrane stability under drought (Farooq et al., 2009). These evidence are in agreement with the present study showed that, application of nanosilica improve the photochemical efficiency might be due to increases the antioxidant defense mechanism (Al-aghabary et al., 2005). Besides these results, Silva (2012) reported that, application of silicon will improve the chlorophyll content under drought condition. Same kind of results is in agreement with Gong et al. (2005) in wheat and Zhang et al. (2018) in tomato under drought stress.

Conclusion

Foliar application of 400 ppm nanosilica had 14 to 18.8% of plant height increment and leaf area index of 14.25% with lesser reduction were noticed in rice under drought. Foliar application of 400 ppm of nanosilica had maximum increment in SPAD value of 16.3% in CO53; wherein CO54 had 10.3% increment in under drought condition. Photosynthetic rate was reduced under drought condition. The variety CO54 had significant reduction in photosynthetic rate of 35.2%; while CO53 had 24.8%. 400 ppm nanosilica application increases the photosynthetic rate by 34.5% inCO54 and 19.2% in CO53 under drought. Transpiration rate was decreased significantly under the drought in both varieties. Maximum rate of transpiration reduction could observe in CO54 (32.2%) over thecontrol. Nanosilica application at the concentration of 400 ppm increases the transpirationrate by 22.45% in rice under drought. Stomatal conductance and PS II photosynthetic efficiency were significantly reduced by 46.4 and 16% in rice respectively. Application of nanosilica (400 ppm) under drought had maximum increases of 68.25 and 15.45% over the drought alone condition in rice.

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