



## ABSTRACT

Potassium nitrate ( $\text{KNO}_3$ ) and silicon dioxide ( $\text{SiO}_2$ ) fortification enhance germination, seedling growth and confer drought tolerance to rice during germination and seedling stages. Rice is a staple cereal grown and consumed across the globe. Nevertheless, drought triggered by a changing climate reduced germination and non-uniform seedling development in directly broadcasted rice production causes poor yield in most drier parts of

# EFFICACY OF POTASSIUM NITRATE AND SILICON DIOXIDE FORTIFICATION FOR INCREASED GERMINATION AND SEEDLING GROWTH OF RICE UNDER DROUGHT CONDITIONS

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## Introduction

Rice (*Oryza sativa* L.) is an essential crop consumed by many of people around the world which accounts for more than half of staple food need of the global population. Considering the essential roles rice plays there is the need for stable and adequate supply for absolute food security, poverty reduction and advancement of financial status of developing nations both in Africa and Asia. The ancient agricultural practices are not enough to meet the increasing food demands of the world's teeming population (Dhillon et al., 2021). Abiotic stresses such as drought, salinity and extreme temperatures affect germination and seedling establishments of rice responsible for yield loss of about 50% and as such reduce world's rice production.

Irregular germination and poor seedling establishment in direct-seeded rice production limit achieving better crop growth and yields principally under drought conditions. Sometimes severe drought stress may lead to total cessation of seedling emergence (Javed et al., 2020).



northern Nigeria. In this study, rice seeds var. FARO44 was fortified with potassium nitrate and silicon dioxide to enhance germination, seedling growth and drought tolerance. The aims of the study include: (i) to evaluate the efficacy of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortification in enhancing germination, seedling growth and biochemical attributes of rice under drought conditions. Seeds were separately fortified in  $\text{KNO}_3$  (2.5% & 5% w/v);  $\text{SiO}_2$  (3% & 3.5% w/v) and their combinations (2.5%  $\text{KNO}_3$ +3.5%  $\text{SiO}_2$ ; 5%  $\text{KNO}_3$ +3%  $\text{SiO}_2$ ). Fortified seeds were then germinated for three weeks with the third week drought conditions being enforced. The fortification experiments were arranged in a completely randomized design with each treatment having four replicates. Afterwards, germination percentage, mean germination time, germination index, seedling growth were evaluated. Equally, total soluble protein, proline and malondialdehyde content were determined. The results revealed that  $\text{KNO}_3$  and  $\text{SiO}_2$  fortifications considerably ( $P \leq 0.05$ ) enhanced seed germination, seedling growth, and biochemical attributes of rice seedlings. Potassium nitrate, silicon dioxide and their combined fortifications improved biochemicals comprising of soluble protein, proline and decreased malondialdehyde content in FARO44 rice under drought. However, combined potassium nitrate and silicon dioxide fortification showed less effect in improving biochemicals of FARO44 rice. Improved seedling growth and biochemicals with reduced malondialdehyde content of FARO44 rice seedlings indicate tolerance to drought conditions. The results of this study found that fortification of FARO44 rice with 2.5% and 5%  $\text{KNO}_3$ , 3% and 3.5%  $\text{SiO}_2$  proved more reliable in improving fast germination, seedling growth and conferring of drought tolerance. It is therefore recommended for farmers to fortify (soak seeds prior to planting) their FARO44 rice seeds with these concentrations before planting to better manage drought which is common during early stages of rice production.

**Keywords:** Potassium nitrate, silicon dioxide, germination, fortification, biochemical attributes.

Most of arid rice-growing areas in northern Nigeria are affected by drought caused by changing climate which led to irregular germination and poor establishment of rice seedlings; this bring about low productivity of rice especially FARO44 variety. There are many methods available for enhancing germination, seedling growth and drought tolerance capability of crops against abiotic stresses such as plant breeding, selection and production of transgenics (Dhillon et al., 2021). However, these methods are costly compared to nutrient seed fortification. Nutrient fortification is a simple physiological



process of soaking seeds in inorganic solutions of nutrients to enhance germination, seedling growth and confer drought tolerance to crops such as rice, maize, wheat and so on (Dhillon et al., 2021).

Previously, it was reported that silicon and potassium nitrate fortification enhanced germination, seedling growth and drought resistance of rice, barley, wheat, maize and sorghum seedlings (Biju et al., 2017; Mondal & Bose, 2022). However, there was a dearth of studies on potassium nitrate ( $\text{KNO}_3$ ) and silicon dioxide ( $\text{SiO}_2$ ) fortification in enhancing FARO44 rice germination and seedling establishment. Therefore, this study was carried out with the aim of (i) to evaluate the efficacy of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortification in enhancing germination, seedling growth and biochemical attributes of rice under drought conditions.

## MATERIAL AND METHODS

FARO44 rice (*Oryza sativa* L.) seed was obtained Lake Chad Research Institute, Maiduguri, Borno State in the north-eastern Nigeria. It is a rice variety with a long grain produced by crossing African local rice and Taiwan Indica rice. It is a high yielding and can mature in 90 days. It can be produced under irrigation and rain fed conditions (Akinwale et al., 2012; Oluwaseyi et al., 2016).

### Seed fortification

Before fortifying the rice seeds with  $\text{KNO}_3$  and  $\text{SiO}_2$ , all beakers and Petri dishes were washed and kept in an oven for 24 hours at 110 °C; while  $\text{KNO}_3$  and  $\text{SiO}_2$  solutions for fortifying the rice seeds were prepared and kept in a fridge freezer (4 °C) before use. Viable selected quality rice seeds were surface sterilized with 0.5% sodium hypochlorite (v/v) for 5 minutes to prevent microbial growth. They were then rinsed thoroughly with distilled water.

Seeds were separately soaked/fortified in solutions of  $\text{KNO}_3$  (2.5% & 5% w/v);  $\text{SiO}_2$  (3% & 3.5% w/v) and their combinations (2.5%  $\text{KNO}_3$ +3.5%  $\text{SiO}_2$ ; 5%  $\text{KNO}_3$ +3%  $\text{SiO}_2$ ) for 8 hours and the systems were kept in the laboratory at temperature 25±2°C and relative humidity of 50-70% (Khan et al., 2019). The solutions were thereafter drained out and the seeds were dried at room temperature of 25 °C for 48 hours (Khan et al., 2019).

### Seed germination and drought induction

Six  $\text{KNO}_3$  and  $\text{SiO}_2$  fortified and unfortified rice seeds (control) were separately germinated in petri dishes lined with Whatman filter paper (60mm size) wetted with 5 ml distilled water for 14 days. Seed is considered to have germinated if the radicle measures about 2 mm (Chunthaburee et al., 2014). Prior to drought condition induction, Kaufmann



(Kaufmann, 1973) formula was used for calculating drought stress solution of -0.3 Mpa using polyethylene glycol (PEG6000). After 14 days of germination, drought condition was induced to the young rice seedlings by watering with 5 ml of -0.3 Mpa PEG6000 for 7 days (Yan, 2015). The petri dishes were kept in the laboratory growth room of temperature  $25\pm 2^{\circ}\text{C}$  and relative humidity of 50-70%, seed germination was recorded for 3 weeks (Khan et al., 2019).

From the data of germination collected, germination percentage (GP), germination index (GI) and mean germination time (MGT) were evaluated (Ghodrat et al., 2013; Aloui et al., 2014; Ruttanarungboworn et al., 2017). Seedling length, root length and shoot length were measured with a ruler while seedling vigour was evaluated (Abdul-baki & Anderson, 1970).

### **Evaluation of biochemical attributes of rice seedlings**

#### **Protein extract preparation**

The slightly modified method of Muchate et al. (2019) was used. Leaves (250 mg) of FARO44 rice seedlings fortified with  $\text{KNO}_3$  (2.5% & 5% w/v) and  $\text{SiO}_2$  (3% & 3.5% w/v) and their combinations (2.5%  $\text{KNO}_3$ +3.5%  $\text{SiO}_2$  and 5%  $\text{KNO}_3$ +3%  $\text{SiO}_2$ ) were first frozen in liquid nitrogen to prevent enzyme activity. Thereafter, the samples were separately ground in icechilled mortar in 2 ml of 62.5 mM Tris-HCl (pH 6.7). The samples were then centrifuged at 11,000 g for 9 min. at  $4^{\circ}\text{C}$ . The supernatant was collected and used for determination of total soluble protein.

#### **Evaluation of protein content**

Total soluble protein was evaluated as described by Ali et al. (2021) with slight modification using Bovine serum albumin (BSA) as a standard. The 1 ml reaction mixture contained 100 $\mu\text{l}$  protein extract and 900 $\mu\text{l}$  Bradford reagent. The reaction mixture was read with a spectrophotometer (Model-Hitachi U-1900, Tokyo, Japan) at a wavelength of 620nm. The content of protein was calculated using the linear equation derived from BSA protein standard curve ( $y=0.77x$ ,  $R^2=0.97$ ).

#### **Evaluation of proline content**

Proline content of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortified rice seedlings grown under drought conditions were evaluated using the slightly modified method described by Bates et al. (1973). A 0.25 g rice seedling was ground in ice chilled mortar in 3 ml aqueous sulfosalicylic acid (pH 7.8). The mixture was centrifuged for 13,000 g for 6 minutes at  $4^{\circ}\text{C}$ . The 2 ml of the supernatant was mixed with 2 ml ninhydrin reagent (30 ml of glacial acetic acid, 1.25 g of ninhydrin and 20 ml 6 Molar  $\text{H}_3\text{PO}_4$ ). The reaction was incubated in water bath at  $100^{\circ}\text{C}$  for 1 hour and



then cooled at room temperature, 4 ml of toluene was added while the mixture was vortexed for 4 minutes at 40 rpm. Following phase separation, the upper layer was used in measuring the proline content and read at absorbance of 520 nm with a spectrophotometer (Model-Hitachi U-1900, Tokyo, Japan). The content of proline was evaluated from a linear equation derived from pure L-proline (Sigma-Aldrich)) standard curve ( $y=2.78x$ ,  $R^2=0.99$ ).

### **Evaluation of lipid peroxidation (Malondialdehyde content)**

Lipid peroxidation of  $KNO_3$  and  $SiO_2$  fortified rice seedlings grown under drought conditions was evaluated with reference to content of malondialdehyde (MDA) and the slightly modified method described by Ali et al. (2021) was used. Fresh leaf sample (0.25 g) was frozen in liquid nitrogen. The frozen leaves were ground in ice-chilled mortar in 3 ml of trichloroacetic acid

(TCA). The homogenate was centrifuged at 11,000 g for 9 minutes at 4 °C. From the supernatant, 2 ml was taken and mixed with 2 ml of 0.67% thiobarbituric acid. The mixture was then heated in water-bath set at 100 °C for 20 minutes and the reaction was swiftly ended by cooling in ice bath. The mixture was thereafter centrifuged for 9 minutes at 11,000 g for suspended impurities to settle. The absorbance of the collected supernatant was read at 532 and 600 nm. The mixture of 0.025% thiobarbituric acid in 10% trichloroacetic acid was used as a blank sample. The content of MDA (mM) was computed with the below formula:

$MDA (mM) = (A_{532} - A_{600}) / \epsilon$ ,  $\epsilon$  is the extinction coefficient ( $=155 \text{ mM}^{-1}\text{cm}^{-1}$ ).

### **Experimental design and statistical analyses**

The  $KNO_3$  and  $SiO_2$  fortification experiments were laid down in a completely randomized design with 5 replications per treatment. The normality of the data was checked with ShapiroWilk test before statistical analyses. One-way analysis of variance (ANOVA) was performed to compare  $KNO_3$  and  $SiO_2$  fortification efficacy on growth parameters and biochemical attributes studied using SPSS (window version 24), and significant differences of means were separated with Duncan's Multiple Range test ( $p < 0.05$ ) (Mondal & Bose, 2022).

## **RESULTS AND DISCUSSION**

### **Efficacy of $KNO_3$ and $SiO_2$ fortification on germination attributes of FARO44 rice under drought conditions**

Potassium nitrate and silicon dioxide fortification and their had significant effect ( $P \leq 0.05$ ) on germination percentage (GP), germination index (GI) and mean germination time (MGT) of rice seedlings under drought conditions as shown in Table 1 below.



Germination percentage of FARO44 rice was significantly enhanced by 2.5% and 5% KNO<sub>3</sub> and 3% and 3.5% SiO<sub>2</sub> fortifications compared with control. Similarly, GP of FARO44 rice was increased by combined fortifications of 2.5% KNO<sub>3</sub>+3.5% SiO<sub>2</sub> and 5% KNO<sub>3</sub>+3% SiO<sub>2</sub> compared with control. However, they had less effect than individual SiO<sub>2</sub> and KNO<sub>3</sub> fortifications.

Additionally, GI of FARO44 rice was significantly improved by KNO<sub>3</sub>, and SiO<sub>2</sub> fortifications compared with control. However, combined fortifications with 2.5% KNO<sub>3</sub>+3.5% SiO<sub>2</sub> and 5% KNO<sub>3</sub>+3% SiO<sub>2</sub> had no significant effect in improving GI of FARO44 rice compared with control. Fortifications with 2.5% and 5% KNO<sub>3</sub> and 3% SiO<sub>2</sub> showed more effect in improving GI of FARO44 rice.

Moreover, MGT of FARO44 rice was significantly lessened by SiO<sub>2</sub> and KNO<sub>3</sub> fortification. compared with control. Fortification with 2.5% KNO<sub>3</sub> followed by 3.5% SiO<sub>2</sub>, 5% KNO<sub>3</sub> and 3% SiO<sub>2</sub> showed more effect in reducing the MGT of FARO44 rice.

**Table 1: Germination attributes of FARO44 rice fortified with KNO<sub>3</sub>, SiO<sub>2</sub> and their combinations under drought**

| Fortification TRTs                           | GP (%)                    | GI                        | MGT (Days)               |
|----------------------------------------------|---------------------------|---------------------------|--------------------------|
| Control                                      | 80 ± 2.44 <sup>b</sup>    | 2.51 ± 0.07 <sup>d</sup>  | 5.01 ± 0.24 <sup>f</sup> |
| 2.5% KNO <sub>3</sub>                        | 100 ± 0.00 <sup>a</sup>   | 3.68 ± 0.08 <sup>a</sup>  | 2.8 ± 0.20 <sup>a</sup>  |
| 5% KNO <sub>3</sub>                          | 100 ± 0.00 <sup>a</sup>   | 3.60 ± 0.08 <sup>a</sup>  | 3.2 ± 0.20 <sup>c</sup>  |
| 3% SiO <sub>2</sub>                          | 100 ± 0.00 <sup>a</sup>   | 3.70 ± 0.05 <sup>a</sup>  | 3.2 ± 0.20 <sup>c</sup>  |
| 3.5% SiO <sub>2</sub>                        | 100 ± 0.00 <sup>a</sup>   | 3.48 ± 0.13 <sup>ab</sup> | 3.0 ± 0.00 <sup>b</sup>  |
| 2.5% KNO <sub>3</sub> +3.5% SiO <sub>2</sub> | 96.1 ± 0.00 <sup>ab</sup> | 2.87 ± 0.09 <sup>cd</sup> | 4.4 ± 0.24 <sup>c</sup>  |
| 5% KNO <sub>3</sub> +3% SiO <sub>2</sub>     | 95.6 ± 0.00 <sup>ab</sup> | 2.88 ± 0.05 <sup>cd</sup> | 4.0 ± 0.00 <sup>d</sup>  |
| Fortification TRTs                           | **                        | **                        | **                       |

Mean values ± SE in the same column followed with similar letters are not significantly different according to DMRT  $P \leq 0.05$ ; SE = standard error of the mean; GP = Germination percentage; GI = Germination index; MGT = Mean germination time; \* = Significant at 5% level of probability; \*\* = Significant at 1% level of probability, TRTs = treatments.

Drought is one of the main causes of germination and yield decline of rice worldwide. Seed germination is a critical stage in rice production especially in rain-fed agricultural systems. Even a moderate drought stress could affect seed germination and seedling emergence and consequently causes yield decline of rice.



Drought decreased germination percentage (GP), germination index (GI) and prolonged the mean germination time (MGT) of FARO44 rice. However,  $\text{KNO}_3$ ,  $\text{SiO}_2$  and their combinations fortification enhanced germination attributes of FARO44 rice. Fortification with combinations of  $\text{KNO}_3 + \text{SiO}_2$  showed less effect in improving germination attributes of FARO44 rice. This might be linked to the low osmotic potential of the fortification solutions thereby slowed down water imbibition into seeds hence affected essential germination processes.

Enhanced GP, GI and shorter MGT of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortified FARO44 rice under drought conditions were due to completion of phases I, II and III of seed germination with their associated physiological and metabolic processes; which include increased water imbibition, biosynthesis of protein and starch within seeds for embryonic growth and development, activation of seed reserve mobilising enzymes that hydrolysed reserve for embryonic growth and faster emergence.

Improved GP, GI and shorter MGT of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortified FARO44 rice under drought conditions showed increased tolerance to drought. Drought suppressed cell division and enlargement, activation of reserve mobilising enzymes, increase pH, causes nutritional and metabolic impairment and ion disorders in rice seedlings (Dien et al., 2019; Javed et al., 2020).

#### **Efficacy of $\text{KNO}_3$ and $\text{SiO}_2$ fortification and their combinations on seedling growth of FARO44 rice under drought conditions**

Potassium nitrate, silicon dioxide fortification and their combinations had significant effect ( $P \leq 0.05$ ) on seedling length, shoot and root length of FARO44 rice seedlings grown under drought conditions as shown in Table 2. Rice seedlings fortified with 2.5% and 5%  $\text{KNO}_3$  and 3.5%  $\text{SiO}_2$  showed more enhanced rice seedling length by more than 2-folds compared with control. Also, 3%  $\text{SiO}_2$  fortification and combinations of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortifications improved seedling length of FARO44 rice compared with control.

Similarly, 2.5% and 5%  $\text{KNO}_3$  and 3% and 3.5%  $\text{SiO}_2$  fortifications enhanced shoot length of FARO44 rice by about 2-folds compared with control. Furthermore, combined  $\text{KNO}_3$  and  $\text{SiO}_2$  fortifications increased shoot length of FARO44 rice compared with control.

Additionally, root length of FARO44 rice was enhanced by  $\text{KNO}_3$  and  $\text{SiO}_2$  fortification by more than 3-folds compared with control. Also, combinations of 2.5%  $\text{KNO}_3 + 3.5\%$   $\text{SiO}_2$  and 5%  $\text{KNO}_3 + 3\%$   $\text{SiO}_2$  fortifications significantly improved root length of FARO44 rice by about 2-folds compared with control.



**Table 2: Growth performance of FARO44 rice seedlings fortified  $\text{KNO}_3$ ,  $\text{SiO}_2$  and their combinations under drought**

| Fortification TRTs                                                   | SL (cm)               | ShL (cm)             | RL (cm)               |
|----------------------------------------------------------------------|-----------------------|----------------------|-----------------------|
| <b>Control</b>                                                       | $7.71 \pm 0.02^f$     | $3.84 \pm 0.10^c$    | $3.61 \pm 0.08^{ij}$  |
| <b>2.5% <math>\text{KNO}_3</math></b>                                | $15.80 \pm 0.04^{ab}$ | $6.56 \pm 0.13^b$    | $8.92 \pm 0.16^a$     |
| <b>5% <math>\text{KNO}_3</math></b>                                  | $16.05 \pm 0.01^a$    | $7.40 \pm 0.03^a$    | $8.67 \pm 0.03^{ab}$  |
| <b>3% <math>\text{SiO}_2</math></b>                                  | $14.58 \pm 0.02^c$    | $6.01 \pm 0.01^c$    | $7.58 \pm 0.22^{def}$ |
| <b>3.5% <math>\text{SiO}_2</math></b>                                | $15.31 \pm 0.05^b$    | $6.22 \pm 0.13^{bc}$ | $9.08 \pm 0.27^a$     |
| <b>2.5% <math>\text{KNO}_3</math>+3.5% <math>\text{SiO}_2</math></b> | $12.41 \pm 0.02^d$    | $4.68 \pm 0.30^d$    | $7.74 \pm 0.17^{cde}$ |
| <b>5% <math>\text{KNO}_3</math>+3% <math>\text{SiO}_2</math></b>     | $11.64 \pm 0.21^e$    | $5.25 \pm 0.27^{cd}$ | $6.38 \pm 0.18^{gh}$  |
| <b>Osmopriming TRTs</b>                                              | <b>**</b>             | <b>**</b>            | <b>**</b>             |

Mean values  $\pm$  SE in the same column followed with similar letters are not significantly different according to DMRT  $P \leq 0.05$ ; SE = Standard error of the mean; SL = Seedling length; ShL = Shoot length; RL = Root length; \* = Significant at 5% level of probability; \*\* = Significant at 1% level of probability; TRTs = treatments.

Drought is one of the environmental pressures that affects rice farming in dry areas and has been a serious obstruction for crop yield in drought threatened ecosystems of the world. Decreased in the growth of rice seedlings is the most distinctive sign of deficit water deficit while better seedling growth is a precursor to productive agriculture.

In this study, drought decreased FARO44 rice seedling growth. However,  $\text{KNO}_3$ ,  $\text{SiO}_2$  fortifications and their combinations countered the grim effect of drought and improved seedling growth of FARO44 rice by enhancing seedling length, shoot length and root length. However, combined  $\text{KNO}_3$  and  $\text{SiO}_2$  fortifications showed less effect in enhancing rice seedling length. This might be due toxicity or higher concentration of combined  $\text{KNO}_3$  and  $\text{SiO}_2$  fortification that reduced water entry into the seeds to stimulate activities of enzymes, embryonic growth and development.

Improved seedling growth of  $\text{KNO}_3$  and  $\text{SiO}_2$  fortified FARO44 rice might be due to fast cell division, enlargement and elongation, improved activation of protective enzymes, osmolytes and low lipid peroxidation in rice seedlings. Silicon,  $\text{KNO}_3$  and SA impart drought resistance to rice, wheat, maize and sorghum (Anwar et al., 2013; Biju et al., 2017; Tayyab et al., 2020). Previously, it was reported that silicon,  $\text{KNO}_3$  and Silicon dioxide application improved seedling growth and drought resistance of rice, barley, wheat, maize and sorghum seedlings (Biju et al., 2017; Fayez & Bazaid, 2014; Dhillon et al., 2021).



### **KNO<sub>3</sub> and SiO<sub>2</sub> fortification and their combinations improve seedling vigour of FARO44 rice under drought conditions**

Potassium nitrate, silicon dioxide fortification and their combinations had significant effect (P

≤ 0.05) on seedling vigour indices of FARO44 rice under drought conditions as shown in Table 3.

Seedling vigour index I (SVI I) of FARO44 rice was improved by KNO<sub>3</sub> and SiO<sub>2</sub> fortification by about 2-folds, and combined KNO<sub>3</sub> and SiO<sub>2</sub> fortification also significantly improved SVI I of FARO44 rice compared with control. Fortification with 2.5% and 5% KNO<sub>3</sub> showed more effect in enhancing SVI I of rice seedlings.

Similarly, seedling vigour index II (SVI II) of FARO44 rice was improved by KNO<sub>3</sub> and SiO<sub>2</sub> fortification, more so combined fortification significantly SVI II of FARO44 rice compared with control. Fortification with 2.5% and 5% KNO<sub>3</sub> showed more effect in enhancing SVI II of rice seedlings.

**Table 3: Seedling vigour indices of FARO44 rice seedlings fortified with KNO<sub>3</sub>, SiO<sub>2</sub> and their combinations under drought**

| Fortification TRTs                           | SVI I                          | SVI II                       |
|----------------------------------------------|--------------------------------|------------------------------|
| Control                                      | 771 ± 0.02 <sup>gh</sup>       | 2341.25 ± 7.05 <sup>g</sup>  |
| 2.5% KNO <sub>3</sub>                        | 1549.46 ± 1.20 <sup>ab</sup>   | 3419.33 ± 10.77 <sup>b</sup> |
| 5% KNO <sub>3</sub>                          | 1543.06 ± 0.12 <sup>a</sup>    | 3603.23 ± 6.10 <sup>a</sup>  |
| 3% SiO <sub>2</sub>                          | 1456.1 ± 1.10 <sup>bc</sup>    | 3390.33 ± 3.43 <sup>c</sup>  |
| 3.5% SiO <sub>2</sub>                        | 1483.4 ± 1.00 <sup>bc</sup>    | 3098.25 ± 11.02 <sup>d</sup> |
| 2.5% KNO <sub>3</sub> +3.5% SiO <sub>2</sub> | 1252.66 ± 11.01 <sup>cde</sup> | 2736.64 ± 3.40 <sup>f</sup>  |
| 5% KNO <sub>3</sub> +3% SiO <sub>2</sub>     | 1162.65 ± 8.01 <sup>ef</sup>   | 3083.5 ± 3.51 <sup>e</sup>   |
| Fortification TRTs                           | **                             | **                           |

Mean values ± SE in the same column followed with similar letters are not significantly different according to DMRT at P ≤ 0.05; SE = Standard error of the mean; SVI I = Seedling vigour index I; SVI II = Seedling vigour index II; \* = Significant at 5% level of probability; \*\* = Significant at 1% level of probability; TRTs = treatments.

Fortification with KNO<sub>3</sub> and SiO<sub>2</sub> and their combinations improved seedling vigour of FARO44 rice under drought conditions. However, combined KNO<sub>3</sub> and SiO<sub>2</sub> fortification showed less effect in enhancing seedling vigour of FARO44 rice. Improved seedling vigour might be due the roles of KNO<sub>3</sub> and SiO<sub>2</sub> in stimulating cell growth and cell expansion.



Previous study found that Si fortified wheat under salinity stress had significantly increased seedling biomass and seedling growth (Azeem et al., 2015). Agreeing these results, the previous study of Farooq et al. (2010) found that  $\text{CaCl}_2$ , KCl and ascorbate fortification increased seedling vigour index of rice as well as increased activities of alpha amylase. Spring maize fortified with SA, extract of Moringa leaf and  $\text{CaCl}_2$  showed improved seedling vigour and seedling growth (Rehman et al., 2015). Kalee and Ali (2024) reported that  $\text{KNO}_3$  fortification of wheat substantially improved seedling vigour index, seedling establishment and seedling growth. Urea and  $\text{KNO}_3$  fortification were effective in imparting drought resistance, enhancing vigour index and growth of Chinese cabbage (Yan, 2015).

Agreeing these results, Tan et al. (2025) reported that rice fortified with silicon dioxide under cadmium stress recorded improved root and shoot dry biomass, seedling vigour and increased activities of POD and CAT. It has been reported that fortifying rice with  $\text{KNO}_3$  and tomato with 0.75%  $\text{KNO}_3$  improved seedling vigour index, shoot fresh and dry biomass, seedling fresh biomass, seedling length, plant height, harvest index, grain yield and phenolic and soluble sugar content (Ali et al., 2020; Dhillon et al., 2021).

**$\text{KNO}_3$  and  $\text{SiO}_2$  fortification and their combinations improve soluble protein, proline and decrease malondialdehyde content in FARO44 rice seedlings under drought conditions**

Potassium nitrate, silicon dioxide fortification and their combinations had significant effect ( $P \leq 0.05$ ) in improving soluble protein, proline and reduction of malondialdehyde (MDA) content in FARO44 rice seedlings under drought as shown in Table 4.

FARO44 rice seedlings fortified with  $\text{KNO}_3$ ,  $\text{SiO}_2$  and combinations had higher soluble protein content compared with control. FARO44 rice seedlings fortified with 2.5% and 5%  $\text{KNO}_3$  had the highest content soluble protein followed by 3% and 3.5%  $\text{SiO}_2$  fortified rice seedlings.

Moreover, proline content of FARO44 rice seedlings was increased by 2.5% and 5%  $\text{KNO}_3$  fortification by more than 3-folds, while 3% and 3.5%  $\text{SiO}_2$  fortification increased proline content of rice seedlings. Combined  $\text{KNO}_3$  and  $\text{SiO}_2$  fortification increased proline content of FARO44 rice seedlings compared with control.

Likewise, malondialdehyde content (MDA) in FARO44 rice seedlings was significantly decreased by  $\text{KNO}_3$ ,  $\text{SiO}_2$  fortification and their combinations compared with control. Malondialdehyde causes lipid peroxidation in plants.



**Table 4: Soluble protein, proline and MDA content of FARO44 rice seedlings fortified with KNO<sub>3</sub>, SiO<sub>2</sub> and their combinations under drought**

| Fortification TRTs                               | Soluble Protein<br>(mg/FW) | Proline<br>(mg/L)  | MDA<br>( $\mu\text{molmg}^{-1}\text{FW}$ ) |
|--------------------------------------------------|----------------------------|--------------------|--------------------------------------------|
| <b>Control</b>                                   | $0.65 \pm 0.01^f$          | $7.04 \pm 0.33^f$  | $0.068 \pm 0.00^a$                         |
| <b>2.5% KNO<sub>3</sub></b>                      | $1.45 \pm 0.03^a$          | $33.68 \pm 1.16^a$ | $0.001 \pm 0.00^c$                         |
| <b>5% KNO<sub>3</sub></b>                        | $1.35 \pm 0.03^b$          | $28.77 \pm 1.02^b$ | $0.001 \pm 0.00^c$                         |
| <b>3% SiO<sub>2</sub></b>                        | $1.22 \pm 0.10^d$          | $22.44 \pm 1.10^d$ | $0.002 \pm 0.00^c$                         |
| <b>3.5% SiO<sub>2</sub></b>                      | $1.25 \pm 0.02^c$          | $23.65 \pm 1.63^c$ | $0.002 \pm 0.00^c$                         |
| <b>2.5% KNO<sub>3</sub>+3.5% SiO<sub>2</sub></b> | $1.08 \pm 0.01^e$          | $21.30 \pm 1.24^e$ | $0.004 \pm 0.00^d$                         |
| <b>5% KNO<sub>3</sub>+3% SiO<sub>2</sub></b>     | $1.08 \pm 0.02^e$          | $21.64 \pm 0.47^e$ | $0.054 \pm 0.01^b$                         |
| <b>Fortification TRTs</b>                        | <b>**</b>                  | <b>**</b>          | <b>**</b>                                  |

Mean values  $\pm$  SE in the same column followed with similar letters are not significantly different according to DMRT at  $P \leq 0.05$ ; SE = Standard error of the mean; MDA = Malondialdehyde; \* = Significant at 5% level of probability; \*\* = Significant at 1% level of probability; TRTs = treatments.

Potassium nitrate and silicon dioxide fortification and their combinations improved soluble protein and proline content of FARO44 rice seedlings while decreased malondialdehyde content in rice seedlings under drought. However, KNO<sub>3</sub> and SiO<sub>2</sub> fortification individually (3% and 3.5% KNO<sub>3</sub>; 3% and 3.5% SiO<sub>2</sub>) had more effect in improving these biochemicals than their combined fortification. These might be associated with toxicity with combined KNO<sub>3</sub> and SiO<sub>2</sub> fortification that hindered initiation of essential biochemical processes in the rice seeds. Improved protein and proline content, and decreased malondialdehyde content in fortified rice seedlings increased drought resistance of rice seedlings.

Agreeing these results, it had been reported by Ali et al. (2021) that KNO<sub>3</sub> and SiO<sub>2</sub> fortified rice recorded about 2-folds higher soluble protein, soluble sugar, proline content and improved resistance to drought (Abdel Latef & Tran, 2016; Pandey & Shukla, 2015). Earlier studies found that Si and SA fortification of rice and maize increased content of protein, proline, glycine betaine, decreased malondialdehyde content and improved drought and chilling resistance (Parveen et al., 2019; Rai-Kalal et al., 2021; Chan et al., 2024).



## CONCLUSIONS

Potassium nitrate, silicon dioxide and their combined fortification of FARO44 rice improved germination, germination index and decreased mean germination time under drought conditions. However, combined potassium nitrate and silicon dioxide fortification showed less effect in improving germination attributes of FARO44 rice. Less effect of combined potassium nitrate and silicon dioxide fortification might be due lower osmotic potential that hindered activation of essential germination processes.

Moreover, potassium nitrate, silicon dioxide and their combined fortification improved seedling growth of FARO44 rice under drought. Improved rice seedling growth might be due to prolific cell division and cell expansion in osmoprimed rice seedlings under drought. Combined potassium nitrate and silicon dioxide fortification had less effect in enhancing rice seedling growth.

Potassium nitrate, silicon dioxide and their combined fortifications improved biochemicals comprising of soluble protein, proline and decreased malondialdehyde content in FARO44 rice under drought. However, combined potassium nitrate and silicon dioxide fortification showed less effect in improving biochemicals of FARO44 rice. Improved seedling growth and biochemicals with reduced malondialdehyde content of FARO44 rice seedlings indicate tolerance to drought conditions. The results of this study found that fortification of FARO44 rice with 2.5% and 5%  $\text{KNO}_3$ , 3% and 3.5%  $\text{SiO}_2$ , proved more reliable in improving fast germination, seedling growth and conferring of drought tolerance. It is therefore recommended for farmers to fortify (soak seeds prior to planting) their FARO44 rice seeds with these concentrations before planting to better manage drought which is common during early stages of rice production.

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