FOLIAR APPLICATION OF MICRONUTRIENTS PROMOTES GROWTH AND YIELD-RELATED ATTRIBUTES OF OKRA (*Abelmoschus esculentus* L.) IN A SLIGHTLY SALINIZED AREA †

[LA APLICACIÓN FOLIAR DE MICRONUTRIENTES PROMUEVE EL CRECIMIENTO Y LOS ATRIBUTOS RELACIONADOS CON EL RENDIMIENTO DE LA OKRA (*Abelmoschus esculentus* L.) EN UN ÁREA LEVEMENTE SALINIZADA]

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SUMMARY

Background: Micronutrients are required in trace amounts, but are importantly associated with plant growth and development. While soil salinity causes a frequent micronutrient deficiency in soil, the condition withholds plant growth, development, and eventually crop production. Since foliar application of micronutrient provides rapid nutrient absorption compared to soil amendments, it may confer straightforward mitigation of salinity stress. However, micronutrients availability to plants under saline conditions has drawn limited attention. **Objective**: To study the role of four micronutrients namely boron (B), zinc (Zn), chlorine (Cl), and silicon (Si) as well as their combinations as foliar application on growth, development, and yield responses of 'okra cv. Nulok F_1' in a naturally very slightly salinized soil. **Methodology:** The research site belongs to Young Meghna Estuarine Flood Plain under the soil of Agro-ecological Zones (AEZ)-18. The area of EC dsm^{-1} 2.39 is used for the cultivation of horticultural and cereal crops. The one-factor experiment was designed in a randomized complete block design with three replications and six treatments. The factor having six different micronutrients and their combinations under saline soil *viz.* T_1 = control (untreated), T_2 = 0.2 % B as solubor®, T_3 = 0.2 % $ZnSO_4$, T_4 = 0.2 % KCl, T_5 = 0.2% SiO_2, and T_6 = 0.2% solubor® B + 0.2% $ZnSO_4$ + 0.2% SiO_2 + 0.2% KCl. **Result**: A number of foliar treatments of micronutrients substantially improved plant height, stem diameter, leaf number, depth of root, fruit length, number of fruits, single fruit weight, yield $plot^{-1}$, and total yield. **Implication:** Among the treatments, Si, and a mixture of solubor® B, Zn, Cl, and Si significantly uphold growth and yield-related attributes of okra indicating them as suitable micronutrients for okra production in salt-affected areas. **Conclusion:** The foliar application of Si and the mixtures of the four aforementioned micronutrients might enhance the growth and yield attributes of 'okra cv. Nulok F_1' under salinity stress.
Keywords: phenological stage; nulok; electrical conductivity; trace element; agroecological zone.

RESUMEN

Antecedentes: Los micronutrientes se requieren en cantidades mínimas, pero están asociados de manera importante con el crecimiento y desarrollo de las plantas. Si bien la salinidad del suelo causa una deficiencia frecuente de micronutrientes en el suelo, la condición impide el crecimiento y desarrollo de las plantas y, finalmente, la producción de cultivos. Dado que la aplicación foliar de micronutrientes proporciona una rápida absorción de nutrientes en comparación con las enmiendas del suelo, puede conferir una mitigación directa del estrés por salinidad. Sin embargo,

† *Submitted February 10, 2022 – Accepted October 17, 2023. http://doi.org/10.56369/tsaes.4238*

ISSN: 1870-0462.
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la disponibilidad de micronutrientes para las plantas en condiciones salinas ha llamado la atención de manera limitada hasta el momento. **Objetivo:** Estudiar el efecto de cuatro micronutrientes, boro (B), zinc (Zn), cloro (Cl) y silicio (Si), así como sus combinaciones como aplicación foliar en las respuestas de crecimiento, desarrollo y rendimiento de 'okra cv. Nulok F1' en un suelo naturalmente muy poco salino. **Metodología:** El sitio de investigación pertenece a Young Meghna Estaurine Flood Plain bajo el suelo de las Zonas Agroecológicas (AEZ)-18. El área de EC dsm-1 2.39 se utiliza para el cultivo de cultivos hortícolas y cereales. El sitio se utiliza para el cultivo de cultivos hortícolas y cereales. El experimento de un factor se diseñó en un diseño de bloques completos al azar con tres repeticiones y seis tratamientos. El factor que tiene seis niveles de diferentes micronutrientes y sus combinaciones en suelos salinos: T_1 = control (sin tratar), T_2 = 0.2 % B como solubor®, T_3 = 0.2 % ZnSO4, T_4 = 0.2 % KCl, T_5 = 0.2 % SiO2, T_6 = 0.2 % solubor B® + 0.2 % ZnSO4 + 0.2 % SiO2 + 0.2 % KCl. **Resultado:** Una serie de tratamientos foliares de micronutrientes mejoró sustancialmente la altura de la planta, el diámetro del tallo, el número de hojas, la profundidad de la raíz, la longitud del fruto, el número de frutos, el peso de un solo fruto, el rendimiento de la parcela-1 y el rendimiento total. **Implicación:** Entre los tratamientos, el Si y la mezcla de solubor® B, Zn, Cl y Si mantienen significativamente los atributos relacionados con el crecimiento y el rendimiento de la okra, lo que indica que son micronutrientes adecuados para la producción de okra en áreas afectadas por la sal. **Conclusión:** La aplicación foliar de Si y las mezclas de cuatro micronutrientes antes mencionados podría mejorar los atributos de crecimiento y rendimiento de 'okra cv.Nulok F1' bajo el estrés por salinidad.

Palabras clave: etapa fenológica; nulok; conductividad eléctrica; oligoelemento; zona agroecológica.

INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench), also known as ladies' finger, belongs to the Malvaceae family and is a warm seasonal crop. The vegetable is economically valuable in many parts of the world due to its dietary significance. Its tender immature fruits are mainly consumed as vegetables (Lamont, 1999; Singh *et al.,* 2014). The crop is rich in vitamins, minerals, protein, iodine, antioxidant, fiber, and has been reported to able to fight against a number of diseases (Cakmak, 2002; Dubey *et al.,* 2017; Liu *et al.,* 2021). The origin of okra is believed to be tropical Africa and often cultivated in South Asia as well. The vegetable can be grown in a wide range of soils. However, it performs well in well-drained and fertile soils along with abundant organic matter. As with most vegetable crops, okra provides better yields if supplemental nutrients are available during different abiotic stresses (Kumar *et al.,* 2010; Adewole *et al.,* 2011). Critical plant functions get limited in case of a shortage of micronutrients resulting in reduced plant growth and lower yield (Maliha *et al.,* 2022).

The eight micronutrients of plants include boron (B), iron (Fe), manganese (Mn), zinc (Zn), chlorine (Cl), copper (Cu), silicon (Si), molybdenum (Mo), and nickel (Ni) that are found in most soils to meet crop requirements (Römheld *et al.,* 1991; Jones *et al.,* 2005). Among them, B, Zn, Cl, and Si alongside other micronutrients were found to be essential in the growth, development, and metabolism of a number of agronomic and horticultural crops (Haleema *et al.,* 2018; Yadav *et al.,* 2020). Borax used as a B source plays numerous roles in plants including cell wall formation, root elongation, water absorption in plant parts, flowering and fruit, and seed quality (Kartal *et al.,* 2007; Riaz *et al.,* 2018; Domingos *et al.,* 2021). Boron cannot easily move around the plant and its deficiency may stunt plant growth and ultimately cause lower yield. A number of vegetable crops like cabbage, cauliflower, and potato are highly sensitive to boron deficiency (Bolaños *et al.,* 2004; Haleema *et al.,* 2018). Zn of $ZnSO_4$ is an essential constituent of over 70 enzymes found to mitigate the harmful effects of biotic and abiotic stresses including salt and drought stress (Duary, 2020). Zinc is essential for producing chlorophyll and plants cannot produce yields in its absence (Trivedi *et al.,* 2013; Brdar, 2020; Singh, 2017; Umair *et al.,* 2020). Silicon on the other hand is applied to increase the yield and quality of a variety of horticultural crops, including tomatoes, cucumbers, and strawberries (Wang *et al.,* 2017). It seems to assist certain plants when they are under stress caused by salinity, drought, high temperature, and inadequate nutrients (Swain *et al.,* 2017; Zhang *et al.,* 2018; Othmani *et al.,* 2021). Chlorine is essential for stomatal regulation, photosynthesis, and for growth of root, and shoot apex (Broyer *et al.,* 1954). The toxicity of high Cl^- concentrations in soil and water on agricultural production is found in coastal areas when it gets excessive. Most Cl^- comes from the saline body of sea and sea area (Chen *et al.,* 2010; Isayenkov *et al.,* 2019). Soil fertilization of these micronutrients is unreachable to plant roots if pH of the soil is high (Wallace *et al.,* 1974). In such a situation, foliar application of micronutrients as opposed to soil application has been well documented on the availability of these nutrients and in reducing environmental hazards as well (Zargar *et al.,* 2019; Niu *et al.,* 2021). Basically foliar feeding is useful only then when roots are unable to supply essential nutrients to the plant body (Goyal *et al.,* 2017; Toor *et al.,* 2020). Therefore, foliar application is proven to be a good substitute for unhealthy soil to provide plant requirements by applying micronutrients directly to the plant parts while facing nutritional hardship (Fageria *et al.,* 2009; Alshaal and Ramady, 2017).

Salinity reduces crop production whereas some micronutrients might be less available for most crop plants which can lead to a number of disorders and lower yield. Salinized soils not only adversely affect plant growth but also affect the development process primarily, by making water less available for uptake by plant roots, causing plant stress (Reza *et al.*, 2014; Uddin *et al.*, 2021). However, the effect of dissolved salts on plants depends on their concentration in water or soils. Salt-affected soils are classified into six classes including non-saline (<2 EC, dS/m), very slightly saline (2-4 EC, dS/m), slightly saline (4-8 EC, dS/m), moderately saline (8-12 EC, dS/m), strongly saline (12-16 EC, dS/m), and extremely saline (>16 EC, dS/m) (Corwin, 2021; Edrisi *et al.*, 2021). When the concentration of salt increases in soil the osmotic pressure of the soil increases as well. As a result, plants are unable to absorb the more salt-concentrated water from the soil even if the soil contains adequate water. Therefore, most plants often suffer from water stress (Nadeem *et al.*, 2013; Zhao *et al.*, 2021), with the exception of some crops having a wide range of tolerance to high salt concentrations due to their ability to extract more water from saline soils (Chen *et al.*, 2018). Moreover, elevated concentrations of any ions, including Na^+, Cl^-, and SO_4^- in plant root zone, create toxicity in plants and induces nutrient deficiencies as limit proper plant growth (Bernstein, 1975; Tian *et al.*, 2020). Micronutrient deficiencies quite often happen in salt-affected areas due to lower ion solubility and thereby lower uptake occurs by plants (Alloway, 2008; Chatzistathis, 2014).To reduce such negative effects, the method of fertilizer application should be considered. Foliar fertilization in this regard could be a more efficient way than any other application method for plant nutrient supplement (Noreen *et al.*, 2018). Production of okra was found to adversely be influenced by the toxic effect of salinity (Elshaikh *et al.*, 2018). Recommendations on micronutrient fertilization for better okra yield under various agro-climatic conditions of the world are available (Darwish *et al.*, 2005; Ritzema, 2008). However, the exact way might or might not be appropriate for its cultivar ‘Nulok F_1’, a local and salt-sensitive variety of Bangladesh under saline conditions. Therefore, taking into consideration of the significance of micronutrients in salinized areas, this investigation was conducted to assess the effect of their different doses on better growth and yield of ‘okra cv. Nulok F_1’ and how foliar fertilization can alleviate soil salinity-deprived problems.

MATERIALS AND METHODS

Experimental area

The research was carried out at Nobogram Agriculture Farm, Sonapur, Noakhali, Bangladesh between September 2020 and January 2021. The research site belonging to the Young Meghna Estaurine Flood Plain under the soil of Agro-ecological Zone (AEZ) of 18 (Fischer *et. al.*, 2006). The soil has been used for various horticultural and cereal crops cultivation.

Plant materials

A high potential variety of ‘okra cv Nulok F_1’ was provided by the company of Syngenta. The seed had a purity of 97% and minimum germination percentage of 65. To prevent the germination loss of salinity, the selected okra seeds were planted in poly bag with non-saline soil. After ten days of germination, the seedlings of approximately 13 cm height were transplanted in the experimental plots on 1st October 2020.

Soil sample collection to test salinity

Initially, soil samples from the soil profile 0-15 cm, from nine locations within the research field were randomly collected and placed on brown colored bags for air drying. The air-dried soil samples were then grounded and passed through a 2-mm sieve. Finally, soil samples were stored in a polythene bag and examined by the Soil Resources Development Institute (SRDI), Noakhali, Bangladesh, to know their physical and chemical properties, along with electrical conductivity (EC), which measures soluble salts concentration in the soil samples (**Table 1**).

Table 1. Physio-chemical compositions of soil tested by SRDI prior to conducting this experiment.

Location	P^H	OM (%)	Ca	Mg	K	Total N (%)	P	S	Zn	B	EC (dSm^{-1})
			meq 100 g^{-1}					μg g^{-1}			
Noakhali, Bangladesh	7.8	0.5	6.0	2.7	0.15	0.04	13.9	12.43	0.55	0.15	2.39
Critical Level	-	-	2.0	0.50	0.12	0.12	7.0	10	0.6	0.2	-
Interpretation*	Slightly basic	Very low	Optimum	Very high	Very low	Very low	Very low	Medium	Low	Low	Very slightly saline

SRDI = Soil Resources Development Institute; OM = Organic matter; meq = milliequivalent; μg = microgram; EC = Electrical conductivity; dS/m = deci-Siemens per meter

Preparation of nutrient solution

As per the treatment details, two grams of solubor® boron were dissolved in one liter of water in a container to make 0.2 percent boron solution and two grams of zinc sulphate were dissolved in one liter of water in another container to make the concentration of 0.2 percent zinc sulphate solution. Similarly, two grams of silicon dioxide and two grams of potassium chloride were dissolved in one liter of water to make the concentration of 0.2% silicon dioxide and 0.2% potassium chloride solution, respectively. Likewise, 0.5 g of zinc sulphate, 0.5 g of solubor® boron, 0.5 g of silicon dioxide, and 0.5 g of potassium chloride were mixed with 1 L of water to prepare the concentration of 0.2% of mixtures solution. All the micronutrient solutions were used in spraying.

Land preparation

The research field was opened at the beginning of September 2020. The land was prepared by plowing and laddering to get a desirable tilt. The corners of the land were spaded and weeds and stubbles were removed from the field. The soil was labeled and turned into seed beds with a total plot area of 55.46 m^2 (9.40 m X 5.90 m). In order to avoid and efficient movement of stagnant of water, drainage channels were constructed around the land. Following the final preparation of the field, the soil was treated with Nuben® @14.35kg/ha to protect the emerged seedlings from the attack of several insect pests.

Experimental design and application method of fertilizer

The one-factor experiment was designed following a randomized complete block design (RCBD) with three replications and six treatments. The okra variety *viz*. 'okra cv. Nulok F_1' was subjected to the following six different micronutrients and their combinations:

T_1 = control
T_2 = 0.2 % Solubor® boron
T_3 = 0.2 % $ZnSO_4$
T_4 = 0.2 % KCl
T_5 = 0.2% SiO_2
T_6 = Mixtures of solubor® boron, $ZnSO_4$, KCl and SiO_2 at 0.2%.

In addition to B, Zn, Si, and Cl, the crop was fertilized with 14 tons of cow dung, 150 kg urea as a nitrogen source, 100 kg triple super phosphate (TSP) as a phosphorus source and 150 kg muriate of potash (MoP) as potassium source and 70 kg gypsum as calcium source ha^{-1}, respectively. The entire amount of cow dung was applied 10 days prior to the final land preparation. The whole amount of TSP and gypsum, 1/4 of urea, and 1/2 of MoP were applied during the final land preparation. The remaining amount of urea and MoP was applied in three equal applications at 20, 40, and 60 days after sowing (DAS) (Alexander 2012). Solubor® boron, $ZnSO_4$, SiO_2, and KCl as a source of B, Zn, Si, and Cl as well as their combination were sprayed during three phonological stages including flowering at 45, fruiting at 60, and harvesting at 75 days after sowing (DAS), respectively according to treatment combinations. Following germination, healthy seedlings of 10 days were transplanted maintaining uniform distance of 30 x 45 cm whereas 30 cm in plant to plant in the same row and 45 cm between rows. Two okra seedlings were transplanted in each small hole.

Intercultural operations

Regular irrigation, weeding, thinning, and hoeing, crop protection measures such as spraying of a neonicotinoid insecticide 'imidacloprid' and a fungicide 'tilt' manufactured by Syngenta and picking of insects with hand and removing of disease affected plant parts were timely done before the data collection.

Data collection

Data on plant growth parameters including plant height, plant stem diameter, branch number, leaf number, length of leaf and petiole, length of fruits, and fruit diameter were observed at 45, 60, and 75 DAS. The plant height of randomly three tagged plants selected from each plot was measured from ground level to tip of a plant by a measuring tape. The mean was thereafter determined and recorded as centimeters (cm). During the collection of plant stem diameter, the circumference of plant stem from 5 cm above of the ground level was measured using a measuring tape and converted to diameter by dividing the circumference with π=3.14159. The average found from randomly selected three plants of each plot of each replication was expressed in cm. In the case of branch number, the average number of branches from three randomly selected tagged plants of each plot was recorded by counting the number of the branches and then an average was made. The number of leaves of three tagged plants taken from each plot was visually counted and the average was recorded. The petiole length from the base of the petiole to the base of the leaf and the leaf length from the tip of the petiole to the leaf apex was measured using a 30 cm long scale and expressed in cm. In both cases, three plants were randomly selected from each plot and an average of three plants was recorded. During measuring fruit length, the length of minimum and maximum-sized fruits randomly taken from three plants was measured using the aforesaid scale from stalk tip to fruit tip and the average length was recorded in cm. In the case of fruit diameter, the circumference of maximum and minimum sized of fruits was measured using a measuring tape and converted to diameter whereas circumference was divided by π=3.14159. The time of the first flower opening was recorded by regular observation during flower opening. The data was recorded from randomly three selected plants of each plot and the average was worked out. Yield-related attributes such as number of fruits per plant, yield per plot, total yield, number of seeds per fruit, weight of 500 seed, and depth of root were recorded as well at the time of final harvesting. In this case, fruits visually inspected were harvested from randomly selected three plants and recorded in a notebook and thereafter the average number of fruits per plant was counted. For total yield calculation, the yield computed from each plot using an electrical balance was converted to ton/ha using the following formula: yield (ton/ha) = [yield per plot (kg)/area of plot (m^2) x 1000)] x 10000. For measuring seed numbers, completely dried matured fruits kept in three randomly selected plants of each plot were cut using a sharp knife and the seeds were collected. The seeds of individual harvested plants were counted manually and the average value of seed number was recorded as the number of seeds per fruit. To know the quality of seeds under each treatment, the weight of 500 seeds was recorded. During this work, the seeds were harvested and dried under a temperature of 35-40°C until the seed weight was stable. All the dried seed lots were weighed for the 100-seed weight (g) value by using a digital scale. The weight of the 100 seeds per plot was multiplied by five and converted into 500 seed weight per plot. During the last harvesting, plants were uprooted to determine of the root depth from the tip to the point. This time, the roots of selected three plants from each plot were measured by using a meter scale. The average value was recorded in cm.

Data analysis

The data were analyzed using IBM SPSS statistics, version 25 software. One-way analysis of variance (ANOVA) was applied to observe if the treatments at different days after sowing (DAS) including 45 DAS, 60 DAS, and 75 DAS had any significant effect on the variables computed. Means of the significant treatments were compared using Tukey HSD of post-hoc test to determine which treatment (s) significantly differ from one or more others. The variation was judged statistically ($p \leq 0.05$ and $p \leq 0.01$). Numerical data are presented as averages ± SEM (standard error of means).

RESULTS

Growth parameters

Plant height (cm)

The analysis of variance showed that the foliar application of micronutrients had significant effect on the height of okra plant (**Figure 1A**). It clearly shows that T_5 (SiO_2 0.2%) and T_6 (0.2% mixture of (solubor® boron + $ZnSO_4$ + SiO_2 + KCl) significantly increased the plant height at 45 DAS (df: 5, 2; f-value: 3.95, and p-value: 0.031) as compared to control. Likewise, T_5 significantly increased the height of plant at 60 (df: 5, 2; f-value: 6.12, and p-value: 0.008) and 75 DAS (df: 5, 2; f-value: 8.05, and p-value: 0.003) as compared to control. The tallest plant was found to be 44.7 cm from T_5 at 45 DAS, 84.0 cm at 60, and 90.1 cm at 75 DAS. On the contrary, the lowest values of 34.7 cm at 45, 54.4 cm at 60, and 62.3 cm at 75 DAS were recorded from the control.

Plant stem diameter (cm)

Plant stem diameter of okra varied significantly among treatments at different DAS (**Figure 1B**). For stem diameter at 45, 60, and 75 DAS, T_5 (SiO_2) showed the highest significant increased stem diameter of the plant compared to the control. The aforesaid significant stem diameter from T_5 was found to be 1.4 cm at 45 DAS, 1.6 cm at 60 DAS, and 1.7 cm at 75 DAS while the diameter of 1.1 cm, 1.4 cm, and 1.5 cm was found from control at 45, 60, and 45 DAS respectively. Moreover, T_5 showed an increased significant difference with T_3 (1.5 cm) and T_4 (1.4 cm) at 60 DAS as well.

Number of branches

No significant response on the number of branches was found among treatments (**Figure 1C**). The data indicated that a maximum insignificant increase in the number of branches was found to be 1.3 when both T_2 and T_6 was applied at 45 DAS. The highest insignificant branch value at both 60 and 75 DAS was seen to be 2.5 from the treatment of T_6 while the minimum value of 1.9 was gained from the control treatment.

Number of leaves

A significant difference at different DAS was found among the treatments in producing leaves (**Figure 1D**). Foliar application of T_6 at 45 DAS significantly increased the number of leaves compared to control. On the other hand, T_4 and T_5 at 60 DAS, and T_5 and T_6 at 75 DAS significantly increased the number of leaves. Hence, it is clearly shown that foliar application

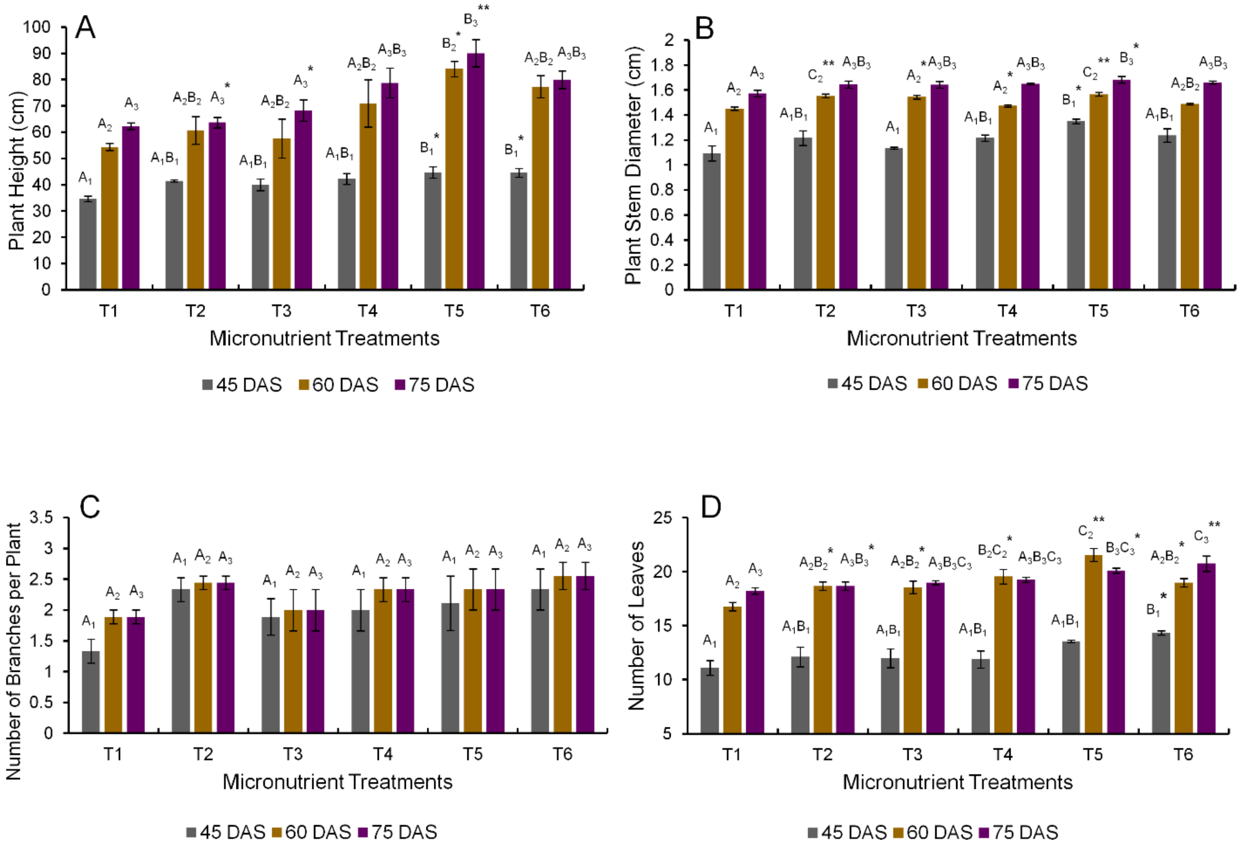

Figure 1. Effect of foliar fertilization of micronutrients under saline soil at 45, 60, and 75 DAS. (A). Plant height; (B). Plant stem diameter; (C). Number of branches plant^{-1}; (D). Number of leaves plant^{-1}. T_1 = Control; T_2 = 0.2% solubor® boron; T_3 = 0.2% $ZnSO_4$; T_4 = 0.2 % KCl; T_5 = 0.2% SiO_2; T_6 = 0.2% mixture (solubor® boron + $ZnSO_4$ + SiO_2 + KCl). Data are the averages of three replications ± standard error mean (SEM). Various letters (A, B, C) shown in the columns denote significant variation (*p<0.05, **p<0.01) over control. The number 1, 2, and 3 used as subscripts corresponds to the number of 45 DAS, 60 DAS, and 75 DAS, respectively.

of T_4, T_5, and T_6 at 45, 60, and 75 DAS significantly increased the leaf number compared to T_1, T_3, and T_4. Statistically, the maximum number of leaves was found to be 14.3 from T_6 at 45 DAS, 21.5 from T_5 at 60 DAS, and 20.7 from T_6 at 75 DAS. On the other hand, the minimum number was observed in T_1 at 45 DAS (11.1), 60 DAS (16.8), and 75 DAS (18.2). However, other treatments did not show significant effect on the leaf number compared to the control.

Length of leaf (cm)

Length of leaf showed a significant difference among treatments at different DAS (**Figure 2A**). Two treatments of T_5 and T_6 at 45 DAS and all the treatments at 60 DAS significantly increased the length of leaf compared with the control. Between T_5 and T_6, the highest significant leaf length was observed to be14.5 cm in T_6 at 45 DAS while the maximum length was found to be 14.8 cm in T_5 at 60 DAS. However, no significant variation between control and other treatments was found during 75 DAS.

Length of petiole (cm)

Petiole length was not significantly affected by the treatments (**Figure 2B**). However, the petiole length at 45 days responded significantly at 10% level of significance. The petiole ranged from 10 cm (T_1) to 13.4 (T_5) at 45 DAS, 10.4 cm (T_1) to 14 cm (T_5) at 60 DAS, and 10.5 cm (T_1) to 12.4 cm (T_5) at 75 DAS.

Length of fruit (cm)

The fruit length significantly responded to the foliar application of different micronutrients (**Figure 2C**). The significantly highest length at 45 DAS was produced by T_5 (14.9 cm), which was statistically identical to T_2 (14.9 cm); while the shortest one was found from T_1 (13.7 cm). Likewise, significantly longer length of fruit at 60 DAS was found from T_5 (15.9 cm) compared to T_1, T_3, and T_4. However, it is interesting to note that the lowest fruit length was detected from T_3 (13.8 cm) while T_1 produced 14.0 cm length of fruit although the difference was not significant. In the case of 75 DAS, significantly the longest fruit was found from T_5 (15.2 cm) followed by T_6 (13.2 cm) whereas the lowest length of fruit was found from T_1 (12.9 cm).

Single fruit weight (g)

The single fruit weight increased due to the significant influence of foliar application of SiO_2 (T_5) compared to the control both at 45 and 60 DAS (**Figure 2D**). Treatment of SiO_2 (T_5) significantly enhanced the single fruit weight to 18.9 g (T_5) from 15.8 g (T_1) at 45 DAS and 20.1 g (T_5) to 17.8 g (T_1) at 60 DAS. However, foliar treatment of other micronutrients on this trait was not significant.

Fruit diameter (cm)

The application of micronutrients did not significantly increase the diameter of the fruit over control **(Figure 2E)**. The diameter of the fruit ranged from 1.7 cm (T_1) to 1.9 cm (T_3) at 45 DAS, 2.2 cm (T_1) to 2.3 cm (T_4) at 60 DAS, and 2.0 cm (T_1) to 2.1 cm (T_5) at 75 DAS.

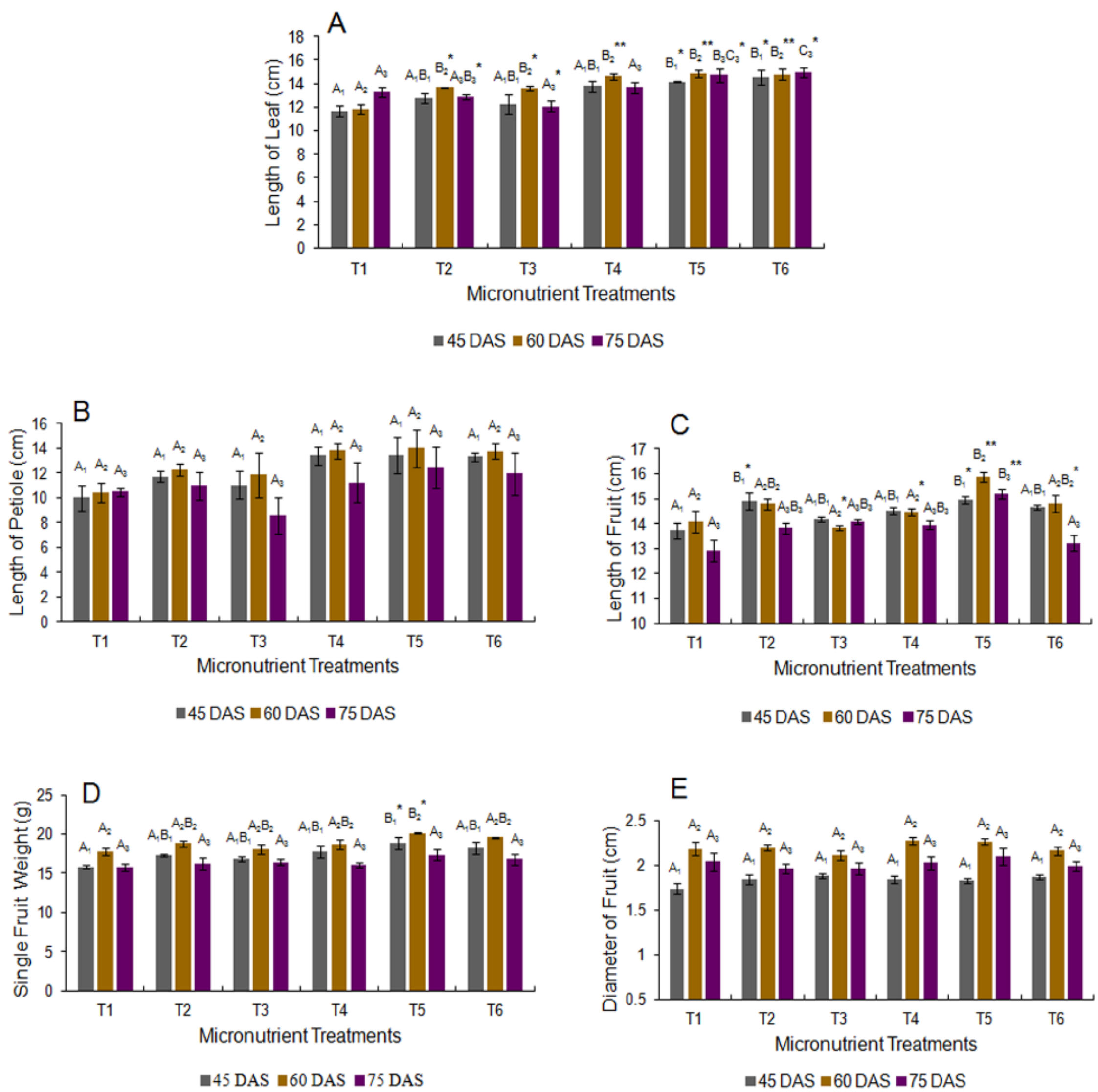

Figure 2. Effect of foliar fertilization of micronutrients under saline soil at 45, 60, and 75 DAS. (A). Length of leaf; (B). Length of petiole; (C). Length of fruit; (D). Single fruit weight; (E). Diameter of fruit. T_1 = Control; T_2 = 0.2% solubor® boron; T_3 = 0.2% $ZnSO_4$; T_4 = 0.2 % KCl; T_5 = 0.2% SiO_2; T_6 = 0.2% mixture (solubor® boron + $ZnSO_4$ + SiO_2 + KCl). Data are the averages of three replicates ± standard error mean (SEM). Various letters (A, B, C) shown in the columns denote significant variations (*p<0.05, **p<0.01) over control. The number 1, 2, and 3 used as subscripts corresponds to the number of 45 DAS, 60 DAS, and 75 DAS, respectively.

Yield parameters

Number of fruits per plant

Number of fruits per plant was significantly affected due to treatments (**Figure 3A**). It showed that T_5 produced the maximum average number of fruits per plant recording 9.5 while the least number of fruits per plant was obtained from the control (8.3), which was similar to T_2 (8.3).

Total yield (ton/ha)

Results in **Table 2** show the effects of treatment mean values of total yield of okra. T_5 showed a significant mean difference with all treatments; whereas T_6 showed a significant difference with the control only. However, no considerable variation in the total yield was found from T_2, T_3, and T_4 as compared to the control.

Number of seeds per fruit

The application of micronutrients had no significant effect in the increasing the number of seeds per fruit compared to the control (**Figure 3B**). However, T_3 showed significant difference with T_4 and T_6. The data recorded showed that the highest significant number of seeds was gained from T_4 (62.3) followed by T_6 (61.7) and T_3 (54.9).

Depth of root (cm)

The depth of the root was measured at the final harvest (**Figure 3C**). A significant highest root depth was found to be 19 cm from T_5 which was statistically similar to T_6; while the minimum value of 16.5 cm was produced by control. The value gained from T_2 (17.0 cm), T_3 (17.9 cm) and T_4 (17.9 cm) was seen to be insignificant compared to the control.

Days of first flower opening

Treatments did not play a significant influence at the time of the first flower opening (**Figure 3D**). It took fewer days (35.7) for the first flower to open when it was treated with the control; whereas 38 days were recorded for T_5; which was similar to all other treatments.

Weight of 500-seed (gm)

The 500-seed weight significantly differed due to the application of various treatments **(Table 2)**. Our findings demonstrated that the significantly highest weight of 500-seed was 36.2 g and 35.9 g, obtained from T_5 and T_6, respectively, compared to T_1 (34.0g).

DISCUSSION

Although the soil fertilization method is ancient, it makes inaccessible nutrients especially in plant roots due to adverse soil salinity (Wallace *et al.*, 1974). In such cases, foliar application can be a better option. Spraying of micronutrients in several studies was previously proved to improve plant growth and development under the adverse conditions of soils including moisture and nutrient unavailability (Li *et al.*, 2009; Niu *et al.*, 2021). In our recent studies, an increased growth and yield by foliar application with several micronutrients has been found in zucchini squash (*Cucurbita pepo* L.) and okra (*Abelmoschus esculentus* L.) cultivation under normal soil conditions (Maliha *et al.*, 2022; Shafiqe *et al.*, 2022). In the current study, our findings showed improved growth and related yield components of okra including plant height, plant diameter, and fruit length with the application of SiO_2 and a combination of solubor® B, $ZnSO_4$, SiO_2, and KCl under the slight saline condition of the soil. Our findings also demonstrate that foliar application of Si and Cl individually improved significant leaf number. At the same time, Si and Zn increased the fruit number and their combined application of B, Zn, Cl, and Si improved both the leaf and fruit number. In a previous study, positive effects on potato growth and its tuber

Table 2. Total yield/ha and 500-seed weight of okra influenced by different foliar applications of micronutrients.

Treatment	Total yield/ha (ton)	% of increase over control	Weight of 500-seed (g)
T_1	11.0 ± 0.2^{A}	-	$34.0 \pm 0.4^{A, B}$
T_2	$11.6 \pm 0.3^{A, B}$	5.75	$34.10 \pm 0.5^{A, B}$
T_3	$12 \pm 0.1^{A, B}$	8.76	33.0 ± 0.5^{A}
T_4	$11.6 \pm 0.2^{A, B}$	6.39	$35.6 \pm 0.1^{B, C}$
T_5	13.2 ± 0.1^{C}	20.82	36.2 ± 0.4^{C}
T_6	12.0 ± 0.3^{B}	10.05	35.9 ± 0.1^{C}

Data are the averages of three replicate ± SEM (standard error mean). The data were analyzed using one-way ANOVA. Tukey HSD tests were performed to find differences between treatments. The values with different letters (A, B, C) indicate significant difference (*p<0.05, **p<0.01). Averages with the same letter (s) within columns do not differ significantly.

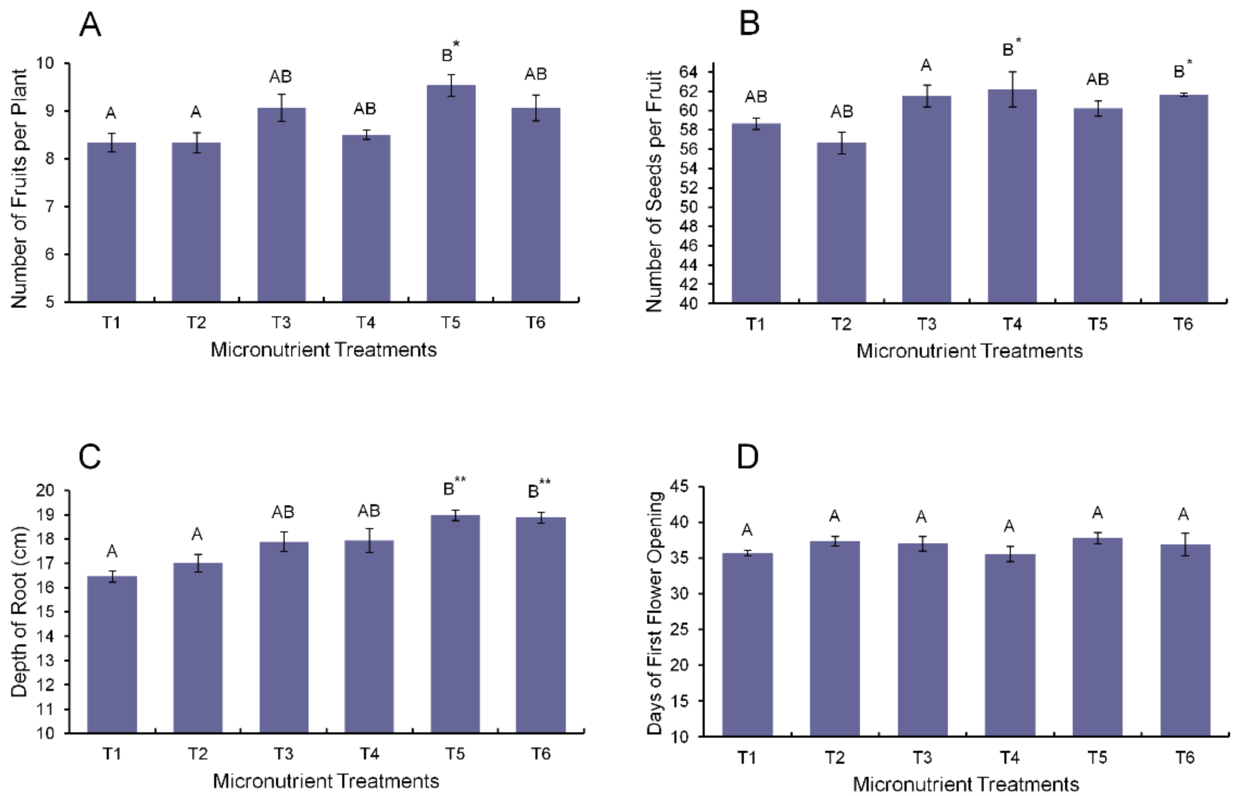

Figure 3. Effect of foliar fertilization of micronutrients under saline soil. (A) Number of fruits per plant; (B). Number of seeds per fruit; (C). Depth of root; (D). Days of first flower opening. T_1 = Control; T_2 = 0.2% solubor® boron; T_3 = 0.2% $ZnSO_4$; T_4 = 0.2 % KCl; T_5 = 0.2% SiO_2; T_6 = 0.2% mixture (solubor® boron+ $ZnSO_4$ + SiO_2 +KCl). Data are the averages of three replications ± standard error mean (SEM). Various letters (A, B, C) shown in the columns denote significant variations (*p<0.05, **p<0.01) over control. Averages with the same letter (s) do not differ significantly.

yield and quality were found with single and combined application of Zn, Si, and B under salinity stress (Mahmoud *et al.*, 2019). Related works with a number of micronutrients under saline soil conditions were previously found to improve plant growth and yield of several agronomic and horticultural crops including rice (*Oryza sativae* L.), spinach (*Spinacia oleracea* L.), and soybean (*Glycine max* L.) (Zayed *et al.*, 2011; Weisany *et. al.*, 2014; Zafar *et al.*, 2022). Parallel results in sweet pepper (*Capsicum annumn* L.) with the foliar application of Si were previously reported as well (Tantawy *et al.*, 2015); whereas Si in saline soil increased the number of fruits (Noreen *et al.*, 2018; Abdelaal *et al.*, 2020). Similar findings were also revealed with the foliar application of B and Zn on okra under non-saline conditions (Kumar *et al.*, 2005) indicating that micronutrients might have a beneficial effect on crop production whatever the soil condition is. In addition, the maximum depth of root in this study was observed sprayed with a combination of the micronutrients that were similar to Si applied individually. A decrease in root growth in a previous report was shown under a saline environment (Zafar *et al.*, 2021). Hence, the increase in the depth of root in our study might be related to the direct effects of foliar application of micronutrients on okra root. Likewise, the foliar treatment of Si significantly enhanced the single fruit weight in saline soil conditions supporting previous research findings stating to give superior fruit length under a saline environment (Víllora *et al.*, 2000; Ali *et al.*, 2014; Ferreira *et al.*, 2019). What is more, the obtained results in this research are consistent with earlier reports whereas Si as individually and in mixture with other micronutrients significantly increased growth and fruit yield of okra under drought and saline soil conditions measured in terms of yield per plot and total yield per hectare (Glenn *et al.*, 2002; Creamer *et al.*, 2005). Moreover, increased growth and yield of musk melon (*Cucumis melo* L.), cucumber (*Cucumis sativus* L.), potato (*Solanum tuberosum* L.), and maize (*Zea mays* L.) were reported from irrigation water, soil, and foliar application of Si and mixture of B, Zn, and Si under saline and normal soil conditions (Salim, 2014; Abd-Alkarim *et al.*, 2017) indicating that Si and the said mixture might have a positive function both in saline and non-saline soil. However, further experiment is required to understand the mechanism of the function of Si in the soils. Previous reports revealed that B and Zn individually and their combination increased 1000-seed weight in untreated saline soil (Alrawi, 2018). In this experiment, the Si individually and the combination with other micronutrients in a saline environment was found to significantly be effective in the weight of 500-seed over control. The result is in accordance with previous findings of 1000-seed weight in okra (Kumar *et al.*, 2021) where it is concluded that 1000-seed weight linearly increased with the foliar application of B and Zn individually and their combinations. The increase in seed weight in this work could be the result of foliar application of micronutrients on okra under a slightly saline environment. It seems that the improvement in growth and development of this okra variety may be due to the foliar performance of micronutrients resulting in good pollination, physiological activities, seed setting as well as structure of grain. However, no significant impact in the current study was observed on the number of branches, days of first flower opening, fruit diameter, and number of seeds fruit^{-1}. The insignificant results might have occurred due to some inevitable issues including water quality, seed quality, pest and disease pressure, environmental factors such as temperature, rainfall, sunlight, fog, or some confounding variable.

CONCLUSIONS

The findings of the present work show the beneficial effects of spraying micronutrients either or in combinations to face slight salinity problems in growing okra plants for having better yield throughout the world, especially in the coastal belt. Among several single and combined foliar applications of micronutrients in this study, the growth and related attributes of 'okra cv. Nulok F_1' responded well towards the treatment of T_5 (SiO_2) followed by T_6 (soluber® B + $ZnSO_4$ + SiO_2 + KCl) in a slightly salinized soil indicating that foliar application of SiO_2 alone or combined with B, Zn and Cl might assist plants better withstand salinity stress which can improve overall plant growth and yield. Therefore, it can be concluded that the application of micronutrients and their individual exogenous combined application might be more effective against salinity stress in enhancing growth and yield attributes of 'okra cv. Nulok F_1' and its related species.

Acknowledgements

We would like to thank Md. Tofail Hossain, Associate Professor, Department of Agricultural Botany, Faculty of Agriculture, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh for his important suggestions and kind revision of the manuscript. The authors are also thankful to agriculturist Mr. Nasim Alam, landowner of Nobogram Agriculture Farm, Sonapur, Noakhali, Bangladesh who graciously allowed to run the research work on his properties.

Funding. This research was partially funded by grants from Research Cell, Fiscal Year of 2020-21, Noakhali Science and Technology University, Noakhali-3814, Bangladesh.

Conflicts of interest. The authors declare no conflicts of interest.

Compliance with ethical standards. The ethics committee of the research cell of Noakhali Science and Technology University, Noakhali-3814, Bangladesh approved this project.

Data availability. Data are available to Dr. Mohammed Nuruzzaman (corresponding author: nzaman.ag@nstu.edu.com), upon request.

Authors' contribution statement (CRediT). Md. Mostafijur Rahman- visualization, methodology**,** data curation, formal analysis and investigation; **Akhinur Shila-**analysis and editing; **Kawsar Hossen-** validation and editing; **Rayhan Ahmed-** review and editing; **Kazi Ishrat Anjum-** review and editing; **Sabia Khan-** analysis and editing; **Mohammed Nuruzzaman-** Conceptualization, formal analysis, methodology, project administration, resources, supervision, visualization, writing- original draft, review, submission, and editing.

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