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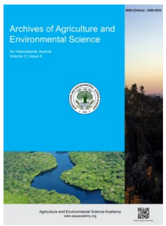

ORIGINAL RESEARCH ARTICLE

Study on the effect of drought and waterlogging conditions on yield and growth of three local varieties of eggplant (*Solanum melongena* L.)

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ABSTRACT

Climate change causes substantial abiotic pressures like drought and waterlogging to reduce eggplant production every year in Bangladesh. Hence, this study aims to investigate the influence of the abiotic stresses on the yield and growth of three local varieties of eggplants including BARI Begun-5, BARI Begun-7 and Purple king in Bangladesh. Also the study aims to find out the proper eggplant variety for the southern and norther parts of Bangladesh. The experiments were carried out using a randomized complete block design (RCBD) with three replications followed by statistical analysis using Statistix 10 software. In comparison to drought and waterlogging conditions, purple king was observed to exhibit larger plant height of 36.5 cm, SPAD value of 57.4, and fruit yield of 1.5 kg/pot when applying a control condition. The results showed that both the waterlogging and drought conditions influenced significantly and reduced the growth and yield of the eggplants. Between them, the waterlogged conditions affected the outputs more. It is worth noting that the BARI Begun-5 was affected by the treatments more than the BARI Begun-7 and Purple king. This study suggests that the purple king variety should be the suitable variety for the southern and norther parts of Bangladesh.

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INTRODUCTION

Around the world, tropical and subtropical locations are popular places to cultivate eggplant (*Solanum melongena* L.), a vegetable that thrives in hot conditions. It is one of the most widely consumed vegetables in Asia, particularly in Bangladesh, where it is widely grown. The eggplant evolved in India and can now be found throughout Asia, with China serving as a secondary source. Furthermore, it is Bangladesh's primary traditional vegetable and the second most important vegetable crop in term of production, following potatoes (Saifullah *et al*., 2012; Sabina *et al*., 2021). The top five eggplant producers are China, India, Egypt, Turkey, and Iran, with total production of 28.4, 13.4, 1.2, 0.82, and 0.75 million tons, respectively (Taher *et al*., 2017). The average yield recorded in Bangladesh is 10.00 tons per hectare, which is less than the yields produced in the other nations (Saifullah *et al*., 2012). While there are many different eggplant cultivars in Bangladesh, their production potential varies and multiple biotic and abiotic stressors seem to have a significant influence on yield (Sabina *et al*., 2021). Abiotic factors that lower productivity include drought, waterlogging, salinity, and extreme heat and cold. Biologic variables that lower productivity include pest and disease infestations (Omolayo *et al*., 2023 & Tian *et al*., 2019). These are the main variables that affect eggplant yields because the crop, in particular, is somewhat sensitive to both drought and waterlogging. As a result of genetic incompatibility, a high level of infertility in the descendants, and a shortage of biological sources of resistance, hybridization procedures have limited potential to produce hybrid eggplants with the requisite stress tolerance; in contrast, genetic engineering may allow for the transfer of desired tolerance characteristics in eggplants (Sabina *et al*., 2021; Iftekhar & Salimullah, 2021).

Due to climate change, unexpected environmental conditions including drought and waterlogging represent a significant threat to humanity. In the context of agriculture, drought is defined as a deficiency of moisture that prevents plants from regularly growing and developing to the whole life cycle. Plant development and growth are significantly impacted by drought, which lowers crop growth rates and biomass buildup (Majid *et al*., 2020). With more variations in rainfall and a drier climate, Bangladesh's northwest region is the most severely hit by the drought. Plants are directly impacted by water stress since it lowers their absorption of nutrients, water, and other plant development hormones (Farooq *et al*., 2008). Waterlogging is an abiotic condition that significantly reduces crop development and output (Sarker *et al*. 2022; Lone *et al*., 2018; Lin *et al*., 2023). As a result of floods, sea level overflow, excessive rainfall, inadequate drainage systems, and other issues cause waterlogging on the land (Lone *et al*., 2018). In Bangladesh, floods occur yearly, in July and August seeing the heaviest flooding. Approximately 20% of the nation is regularly submerged by river floods, with exceptional years submerging up to 68 percent of the country. Global climate change is causing waterlogging to become more prevalent, regular, and unpredictable (Jackson & Colmer, 2005). Waterlogging causes plant reactions such as elevated internal ethylene level, inadequate stomatal activity, diminished leaf, root, and shoot growth, alterations in osmotic potential and food absorption, and reduced chlorophyll levels and photosynthesis (Ashraf *et al*., 2011 & Malik *et al*., 2001). The main effect of waterlogging is oxygen shortage, which makes crops like tomatoes, eggplants, and Annona species more sensitive to changes in development and production (Walter, 2004 & Ezin *et al*., 2010).
Sarker *et al*. (2022) evaluated ten hybrid varieties of eggplant under short-term waterlogged condition. They maintained waterlogging condition for 96 hours. with a depth of 25 mm. The study showed that there was a great influence of waterlogging on the development and growth of ten hybrid varieties. They have identified that BARI hybrid Begun-6 showed higher waterlogging tolerance than others. Israt *et al*. (2020) investigated the influence of nitrogen fertilizer concentration on the growth and development of an eggplant (Tal begun) variety. The results showed that the use of urea fertilizer influenced the growth of eggplant significantly. Sarker *et al*. (2023) investigated the effect of waterlogging on the growth and yield of eggplants (BARI Begun-4, Singnath and Tal begun). These eggplants were subjected to waterlogging conditions for a maximum of 12 days. The results showed that the waterlogging condition influenced growth and production of these three varieties significantly. Among all, Singnath variety performed better in waterlogging conditions considering yield per plant.
Even though eggplant is very important to the economics and nutrition, its yield is highly dependent on soil conditions, varietals, and climate. Information on how the local varieties of eggplant respond to various abiotic challenges in terms of development and yield is still lacking, leading to a need for research. The study aims to evaluate the development and production of three different local eggplant varieties under drought and waterlogging stresses and to identify the suitable variety of the local eggplant. A randomized complete design (RCBD) with three separate replicates was used. Statistical analysis is carried out to analyze the data. It is expected that this study will contribute to generating knowledge on the environmental effects on crop production.

MATERIALS AND METHODS

Experimental location

The Agroforestry and Environmental Science Field Lab at Sher-e-Bangla Agricultural University in Bangladesh served as the experimental site, and the studies were conducted there in 27 sets of plastic pots (Dia: 30 cm and height: 25 cm). The experiment was carried out between October 2019 and March 2020, during the Rabi season. The weather is somewhat cold and there is an abundance of sunshine during Rabi season. The experimental location of Agargaon, Dhaka-1207, was located at 23^{o}75' N latitude and 90^{o}34' E longitude, at an elevation of 8.5 m above sea level.

Design and layout of the experiments

The study used a two-factorial design with three repetitions based on an RCBD approach (Sarker *et al*. 2022). Two factors such as eggplant varieties (V1= BARI Begun 5, V2 = BARI Begun 7 and V3 = Purple king) and treatments (control as T1, drought stress as T2 and waterlogging stress as T3) were considered. As per RCBD, this experiment involved the usage of a total of 27 containers. Three equal blocks made up the experiment area, and nine pots were placed over each block. Two pots and two blocks were separated by 0.4 m and 0.75 m, respectively.

Local eggplant varieties

This study focused on three eggplant varieties: Purple king, BARI Begun-7, and BARI Begun-5.

Soil and fertilizers

The selected soil has a medium texture and is equipped with suitable irrigation systems. SAU Field provided the sandy loam soil that was used in the experimental pot. The utilized soil had an average pH of 6.5 and a temperature of roughly 29 °C. Urea, TSP (Triple super phosphate), potash and cow dung were employed in the experiments.

Seedling and pot preparation

Bangladesh Agriculture Research Institute (BARI), Joydebpur, Gazipur is the source of the seeds for three types of the varieties. The seeds were planted in various plastic pots on November 13, 2019, in order to raise the seedlings. We utilized the sandy loam soil to prepare a container. There were no stubbles or weeds in the soil at all. Following a complete crushing and sun-drying process, the soil was thoroughly combined with MP (250 gm), TSP (500 gm), urea (350 gm), and decomposed cow dung (3:1). To keep pathogens out of the soil, 25 g of Sevin powder was applied. Each plastic container contains approximately 7 kg of the component mixture. Fifteen days before transplanting, the pots were completely filled.

Application of the treatments

During the flowering period at 45 days after transplanting (DAT), the plants experienced both drought and waterlogging. The daytime temperature during the studies ranged from 25 to 29°C while the nighttime temperature fluctuated from 15 to 20° C, and the humidity varied from 44 and 67%. When the plants were ready to flower, they were split into three groups. Nine potted plants from one group were submerged in a water basin (tank) that was filled with tap water to cause waterlogging. One inch of water was kept above the surface of soil in the pot. The water level in the tank, measured from the bottom to the surface of the pot soil, was 20 cm. Eight days were allotted for the waterlogging (45 to 53 DAT). For eight days (45 to 53 DAT), irrigation was not provided to the second group of plants (nine pots). This was done to simulate a drought. A moisture measuring meter (PMS-714) was used to measure the soil moisture during drought stress. At the moment of drought stress release, soil moisture levels ranged between 9 and 11%. The third group of plants consisting of nine pots were cultivated as the control.

Intercultural operations

Every pot was weeded when necessary to maintain the plant free of pests, illnesses, and weeds, which can significantly reduce the number of eggplants produced. Dithane M45 @ 0.6 ml/L was applied to the plants in order to prevent unintended disease issues. Tufgor @ 1.5 ml/L controlled the leaf feeder. To control diseases and pests, fungicides and insecticides were applied twice: once during the vegetatively growing stage and again during the early flowering stage.

Date collection

When eggplant fruits reached full maturity and showed a rich violet color and firm firmness, they were harvested. At 85 DAT, harvesting began, and it continued until 100 DAT. Data including plant height (cm), leaf chlorophyll content (SPAD value), fruit number and yield per pot (Kg) were recorded. At 65 and 80 days after transplant, a meter scale was utilized to measure the plant height (PH) of each plant and the average was calculated. PH was considered from its base to its tip. A portable SPAD 502 Plus meter (Konica-Minolta, Tokyo, Japan) was employed to measure the leaf chlorophyll content. The SPAD reading was repeated three times for each measurement, and the average was computed. The weight of the eggplants was measured using a balance.

Statistical analysis

Software called Statistix 10 was used to statistically analyze the collected data. Least significant difference (LSD) was used to evaluate treatment differences at the 5% significance threshold for each analysis of variance.

RESULTS AND DISCUSSION

Parametric significance on eggplant height

The p value of the associated factors needs to be smaller than 0.05 for the responses to be considered significant (Al-Amin *et al.*, 2021). It is known that a low coefficient of variance (CV) value indicates excellent estimating precision. The findings of the ANOVA for PH are shown in Table 1. Table 1 shows that treatment (0.0001) and varieties (0.0001) have a substantial impact on plant height because their P values are smaller than 0.05. With a p value of 0.0436, the interaction of variety and treatment is significant for PH as well. Varieties (322.58) had a greater impact on PH than treatments (41.19) and their interaction (3.15). A comprehensive assessment of the factors for pH is confirmed by a low CV value of 2.72%. So, it is clear that both the drought and waterlogging conditions affect the growth of the eggplants significantly.

Effect of treatments on eggplant height

Figure 1(a-c) depicts the effects of treatments on eggplant height of BARI Begun-5, BARI Begun-7 and Purple king at 65 and 80 days. Generally, T1 condition accelerates the eggplant height, but both T2 and T3 conditions suppress it for all varieties. In Figure 1a, T1 condition yields the maximum PH of 28.4 cm at 65 days and for V1. When T3 condition is applied, this height drops to 23.2 cm. This happens because T3 condition inhibits root respiration and photosynthesis, both of which are vital for eggplant growth. Because both plant cell count and stomatal conductance are reduced (Jiawei *et al.*, 2020). T2 condition exhibits a somewhat larger PH (25.6 cm) than T3 condition. A high PH of 32.3 cm is recorded for V1 when applying control condition (T1) at 80 days, whereas PH of 27.2 cm and 23.8 cm are reported for the situations of T2 and T3 treatments, respectively. According to Figure 1b, in 65 days, the largest PH is 31.5 cm under control for V2. Under T3 and T2 circumstances, however, this number drops to 28.1 cm and 29.8 cm, respectively. A PH of 36.7 cm is obtained for the TI at 80 days, whereas PH of 32.8 cm and 31 cm are recorded for the situations of T3 and T2, respectively. T1 condition at 65 days for V3 shows the

Table 1. ANOVA data of plant height of eggplant.

Factors	DF	SS	MS	F	P
Rep	2	8.332	4.166		
Variety	2	439.843	219.921	322.58	0.0001
Treat	2	56.17	28.085	41.19	0.0001
Variety × Treat	4	8.579	2.145	3.15	0.0436
Error	16	10.908	0.682		
Total	26	523.832			
CV			2.72%		

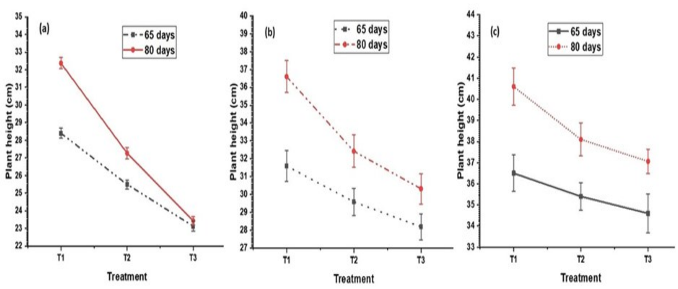

Figure 1. *Effects of treatments on plant height of (a) V1, (b) V2 and (c) V3 at 65 and 80 days.*

Table 2. ANOVA data of SPAD value of eggplant.

Factors	DF	SS	MS	F	P
Rep	2	4.97	2.485		
Variety	2	241.116	120.558	174.56	0.0001
Treat	2	85.716	42.858	62.05	0.0001
Variety × Treat	4	8.728	2.182	3.16	0.043
Error	16	11.05	0.691		
Total	26	351.581			
CV			1.58%		

Table 3. ANOVA data of fruit numbers of eggplant.

Factors	DF	SS	MS	F	P
Rep	2	4.667	2.3333		
Variety	2	92.667	46.3333	139	0.0001
Treat	2	20.667	10.3333	31	0.0001
Variety × Treat	4	5.333	1.3333	4	0.0195
Error	16	5.333	0.3333		
Total	26	128.667			
CV			4.32%		

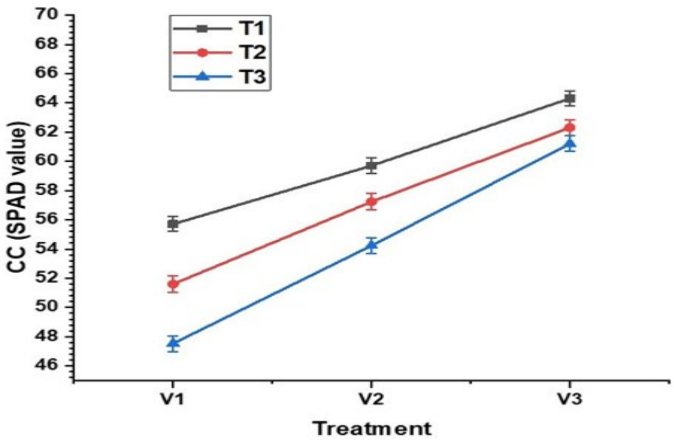

Figure 2. *Effects of treatments on chlorophyll content (SPAD value).*

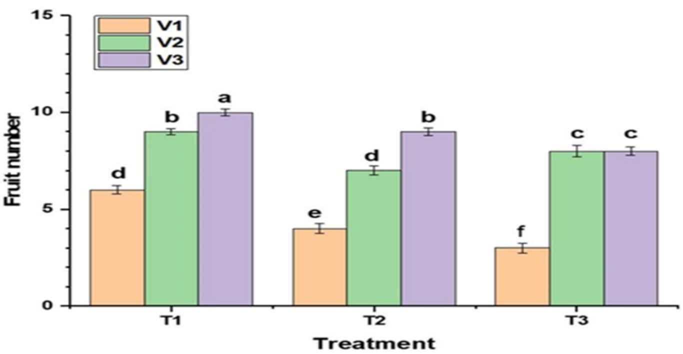

Figure 3. *Effects of treatments on fruit number (FN) at the fruiting stage with error bars.*

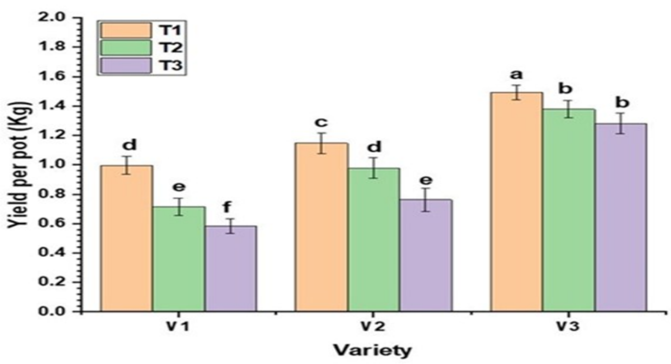

Figure 4. *Effects of variety on fruit yield at the fruiting stage with error bars.*

largest PH of 36.5 cm, which drops to 34.9 cm when employing the T3 condition, as illustrated in Figure 1c. In comparison to T3 condition, the PH for T2 condition is higher, which is 35.4 cm. At 80 days, a high PH of 40.5 cm is achieved for the control group, but T2 and T3 conditions are associated with PH of 38.2 cm and 37.7 cm, respectively. To summarize, waterlogging reduces the growth of all kinds more than drought does. Furthermore, the purple king variety had the highest tolerance to both drought and waterlogging stresses.

Parametric significance on SPAD value

The SPAD value at 67 days is displayed in Table 2 based on the ANOVA results. Table 2 shows that treatment (0.0001) and variety (0.0001) have a substantial impact on SPAD values. With a p value of 0.043, the interaction between treatment and variety is significant for SPAD values as well. The value of SPAD is more influenced by variety (174.56) than by treatment (62.05) and their interaction (3.16). An accurate examination of the parameters for the SPAD value is generated since CV value is 1.58%. It is obvious that both waterlogging and drought conditions had great impact on SPAD value that followed the study done by Sarker *et al.* (2022).

Effects on treatment on SPAD value

Figure 2 illustrates the effects of treatments on chlorophyl content (CC) of several varieties of eggplant. Overall, a high number of chlorophyl is found for all the varieties when T1 applies. Purple king eggplant contains more chlorophyl compared to others. The largest SPAD value (64.3) is obtained for T1 condition, whereas the smallest SPAD value of 47.4 is calculated for T3 condition. To conclude, waterlogging (T3) condition affected the SPAD value of all the eggplant varieties more compared to the drought condition (T2) and the purple king eggplant maintained a high chlorophyl content at any condition. This is because prolonged waterlogging conditions inhibit oxygen supply and chlorophyllase activities reported by Omolayo *et al.* (2023) & Tian *et al.* (2020).

Analysis of eggplant's yield

Factors affecting fruit number (FN)

Table 3 presents information on ANOVA data for FN. In Table 3, a FN is strongly impacted by variety (0.0001) and treatment (0.0001). Their interaction's p value (0.0195) suggests that it has an impact on the quantity of fruits. The parameters for FN are precisely analyzed with a low CV value of 4.32%. It is obvious that the number of eggplant fruits reduced significantly due to both drought and waterlogging conditions that have been reported in the studies by Sarker *et al.* (2023) and Sarker *et al.* (2022).

Effects of the treatment on FN

Figure 3 demonstrates the influence of treatments on eggplant fruit numbers at fruiting stage. Overall, a small FN is recorded for T3 at any variety, whereas a high FN is found for control (T1).

Table 4. ANOVA data of eggplant yield.

Factors	DF	SS	MS	F	P
Rep	2	0.01362	0.00681		
Variety	2	1.79892	0.89946	247.66	0.0001
Treat	2	0.50979	0.25489	70.18	0.0015
Variety × Treat	4	0.0464	0.0116	3.19	0.0416
Error	16	0.05811	0.00363		
Total	26	2.42683			
CV			4.63%		

For V1, a FN of 6 is detected at T1, and when T2 is applied, the FN drops to 4. For T3, there is an additional decrease in FN to 3. T1 records a FN of 9, while T2 records a FN of 7 for V2. Subsequently, T3 exhibits an increase in FN. For V3, T1 has the most FN of 10, followed by T2 (9) and T3. T3 has the lowest fruit number of 8, which is observed at V3. To conclude, the waterlogging influenced the FN more than the drought conditions. BARI Begun-7 showed a higher resistance to waterlogging conditions than both BARI Begun-5 and Purple king. However, Purple king showed the highest resistance to stress while the BARI Begun-5 revealed the lowest resistance. Sarker *et al.* (2023) reported that waterlogging conditions reduced the number of fruits per plant for BARI Begun-4, Tal begun and Singnath begun. Aujla *et al.* (2007) found that eggplants cultivated in drought conditions had lower fruit set than those produced in regular irrigation. Similar results were seen in eggplant by Zayova *et al.* (2017) as a result of lower photosynthetic activities. According to Ezin *et al.* (2010), certain eggplant species have lower fruit set and enlargement due to soil waterlogging. Due to worse nutrient transfer, Kirnak *et al.* (2002) also reported less fruits on eggplant grown in waterlogging conditions.

Factors affecting eggplant yield

Table 4 presents data on ANOVA of the eggplant yield. Table 4 indicates that treatment (0.0015) and variety (0.0001) have a substantial impact on fruit output. Their interaction is significant for fruit yield, as evidenced by its p value (0.0416), which is less than 0.05. Due to a high F value, variety (247.66) has a greater impact on fruit yield than the treatments and their interaction. A detailed examination of the parameters for fruit yield is provided by a low CV value of 4.63%. The statistical analysis revealed that both the drought and waterlogging conditions significantly affected the production of eggplants following the studies by Sarker *et al.* (2022) & Sarker *et al.* (2023).

Effects of the variety on eggplant yield

Figure 4 depicts how diversity affects fruit yield during the fruiting stage. V3 yields a high rate of production overall, while V1 yields a poor amount of fruit under various treatment circumstances. V3 has the greatest fruit yield at T1, weighing 1.5 kg/pot, whereas V1 has the lowest, weighing 1 kg/pot. A large fruit yield of 1.4 kg/pot is recorded for V3 at T2, whereas V2 and V1 only produce 0.98 kg and 0.7 kg/pot, respectively. At T3, V3 has the greatest fruit output (1.3 kg/pot), while V1 has the lowest fruit yield (0.6 kg/pot). It is concluded that in both drought and waterlogging situations, purple king (V3) can produce a lot of fruit, whereas V1 (BARI Begun-5) can only produce a small amount. The varieties yielded the least fruit when there was waterlogging. The previous studies (Sarker *et al.*, 2023 & and Sarker *et al.*, 2022) on other varieties of eggplant also reported that waterlogging significantly reduced the production of the eggplants. The poor development of the eggplant is observed during the waterlogging conditions, which results in a less yield of the eggplant.

This is because excessive water can damage the root following a less nutrient intake. In addition, the oxygen supply is limited in waterlogging conditions. The prolonged waterlogging causes the removal of air from the soil. Most importantly, excessive water around the roots can hamper the water intake by preventing the osmosis process (Ding *et al.*, 2020, Zhou *et al.*, 2020 & Tian *et al.*, 2019). Due to cell elongation and expansion caused by hindered mitosis, decreased growth and yield qualities resulted from the drought (Hussain *et al.*, 2008). When drought stress was applied to the maize plants during the tasseling stage, yield/plant, biological yield/plant, and harvest index all decreased significantly (Anjum *et al.*, 2011). Bafeel & Moftah (2008) speculate that drought stress may have a negative impact on eggplant output because of a decrease in vegetative growth.

Conclusion

The present study aimed to assess the effects of two important abiotic conditions on eggplant yield characteristics and vegetative growth. The following conclusions can be drawn after taking the results of the current experiment into consideration.

- It is seen that the local varieties including BARI Begun-5, BARI-7 and Purple king significantly were affected by the treatment. Among the three selective local varieties, the Purple king has higher tolerance against the abiotic stresses compared to BARI Begun-5 and BARI Begun-7. So, the Purple king can be grown in northern and southern parts of Bangladesh in summer season.
- It is found that waterlogging conditions can affect the three varieties of eggplant more than the drought conditions. In control, the Purple king showed a high yield of 1.5 kg/pot, which reduced to 1.3 kg/pot in waterlogging conditions.

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DECLARATIONS

Authors contribution

Conceptualization, F.T.Z; Methodology, F.T.Z; Software, F.T.Z; Formal analysis, F.T.Z and N.N; Investigation, N.N, T.S,; Data curation, F.T.Z and N.N; Writing-original draft preparation, F.T.Z; Writing review and editing, N.N, TVVLN R; Visualization, N.N and TVVLN Rao; Supervision, N.N; project administration, N.N.

All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare no conflict of interest.

Ethics approval: This study did not involve any animal or human participant and thus ethical approval was not applicable.

Consent for publication: All co-authors gave their consent to publish.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: Available or not available?

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