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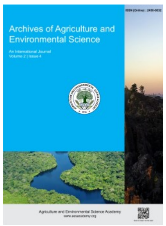

ORIGINAL RESEARCH ARTICLE

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Morpho-physiological response of maize (*Zea mays* L.) genotypes under aluminium stress at early seedling stage

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ABSTRACT

This study investigated the morpho-physiological responses of five maize (*Zea mays* L.) genotypes to aluminum stress during the early seedling stage. The experiment, conducted at the Plant Physiology Laboratory in the Department of Crop Botany at Bangladesh Agricultural University, Mymensingh, followed a two-factor completely randomized design with aluminum concentrations (0 µM as control, 100 µM, and 200 µM) and five maize varieties (Konok, Kaveri -50, BWMRI-1, BHM-14, and BHM-16). Variety Konok exhibited superior overall performance across experimental parameters, while aluminum stress at 200 µM consistently decreased seed germination and seedling growth compared to the control at all recording stages. Variety Konok without aluminum stress demonstrated the highest values for root length (28.23 cm), shoot fresh weight (4.35 g), shoot dry weight (0.53 g), root fresh weight (8.18 g), root dry weight (1.21 g), total fresh weight (12.56 g), total dry weight (1.74 g), vigor index (5106.7). Conversely, under aluminum stress (200 µM AlCl3), the lowest values were observed in root length (14.70 cm), shoot length (15.38 cm), seedling length (31.50 cm), shoot fresh weight (1.79 g), shoot dry weight (0.20 g), root fresh weight (1.96 g), root dry weight (0.47 g), total fresh weight (3.84 g), total dry weight (0.67 g), vigor index (2592.7), and various stress tolerance indices. In summary, the study suggests that the maize variety "Konok" exhibits greater enhancement during the early seedling stage when grown without exposure to aluminum stress, emphasizing its potential for improved performance under normal conditions.

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INTRODUCTION

Maize (*Zea mays*) is one of the most important cereal crops in the world and accepted as the second most important cereal crop in Bangladesh for its higher productivity and use. The total annual production of maize in Bangladesh is 40.15 lac tons from 11.65 lac acres of land in the fiscal year 2019-2020 and the production is increasing year by year (12.5% yield was increased during 2019-2020 fiscal year) (BBS, 2021). The benefit-cost ratio was greater than 2, and the average net return per acre was 32,392 BDT. Farmers use more organic manure, but less chemical fertilizers than recommended doses. The outcomes also disclosed a profit efficiency score of 0.71, which indicates a 29% profit inefficiency. The average net benefit was 32,392.40 BDT/acre and profit-loss 16975.99 BDT/acre (Adnan *et al.*, 2021). Soil acidity is a result of the chemical element aluminum (Al).

In acidic mineral soils, aluminum, a rhizotomy ion, can impede plant growth and productivity (Cunha *et al.*, 2018). After oxygen and silicon, aluminum makes up 8% of the earth's crust. It combines with air and water to generate oxides and hydroxides. (Kvande, 2015; Bojórquez-Quintal *et al.*, 2017). According to Rahman *et al.* (2018) and Pidjath *et al.* (2021) Al toxication harms the plasmalemma of root cells, which prevents them from absorbing water and nutrients.

Maize yields in the tropics can be reduced by 38–80% as a result of high soil acidity (Tandzi *et al.*, 2015; Tekeu *et al.*, 2015). One strategy to boost growth and production in regions with high acidity levels is to develop maize that is highly Al saturated and tolerant of acidic soil. Due to the organic matter's breakdown, acidic soils include a variety of organic acids. In acidic soils, aluminum is released into the ground via hydrolyzing Al hydroxides, silicates, and Al bound by organic matter (Pavlů *et al.*, 2021). Xu *et al.* (2017) reports that maize tolerant to high levels of aluminum can exude organic acids and organic phosphorus, lower the capacity of the cell walls to bind Al^{3+}, increase the pH of the rhizosphere, which decreases the availability of Al, and detoxify the soil. The agronomic characteristics and production potential of each variety of maize grown on land with high Al saturation will vary. The relationships that plant have with their surroundings determine their phenotypic and yield (Adnan *et al.*, 2020).

Additionally, variations in the maize plant's tolerance index to aluminum stress might result from interactions between genes and the environment. Al inheritance in maize is decided genetically and by root growth, according to Coelho *et al.* (2019). The citrate transporter encoded by ZmMATE1 and ZmMATE2 regulates maize's ability to withstand Al stress (Sun *et al.*, 2020; Vasconcellos *et al.*, 2021). Additive and non-additive genes affect root length, a crucial characteristic for assessing maize stress tolerance to aluminum (Ndeke and Tembo, 2019). Al concentrations varied from 6 to 16 ppm when used in nutrient culture experiments based on relative root development to assess the tolerance level of maize genotypes. In acid soils with high Al saturation, the issue of relatively poor maize productivity must be solved by using maize types that are tolerant of Al stress. As a result, in order to create maize varieties that are resistant of aluminum, it is essential to assess the development and tolerance of maize lines under this stress.

It is mainly used for human consumption and animal feed and also an important source of carbohydrates, protein, iron, vitamin B and minerals. It's consumed as a starchy base in a wide variety of porridges, grits, and beer. Green maize is eaten parched, baked, roasted or boiled; playing an important role in filling the hunger gap after the dry season. Maize plant has also economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce food and non– food products (Tembo, 2018). In the industrialized countries it's used as raw material for manufacturing pharmaceutical and other industrial products (Akbar *et al.*, 2016). It is not only used as human food and animal feed but also widely used for corn oil production, corn starch industry, baby corns etc. (Arora *et al.*, 2017). The selection of seedlings in nutrient solution is a rapid screening method based on NRG, developed to screen for Al tolerance in several crops.

MATERIALS AND METHODS

Site and time of the experiment

The study was conducted between April 2021 to June 2021 at the Plant Physiology Laboratory of the Department of Crop Botany, Bangladesh Agricultural University, Mymensingh.

Experimental materials

The test crops under investigation were five varieties of maize cultivated in Bangladesh. The seeds of all cultivars were collected from different seed company of Bangladesh. The following five varieties of maize were used as planting materials for the present study: V_1: Konok, V_2: Kaveri-50, V_3: BWMRI-1, V_4: BHM -14, V_5: BHM-16.

Experimental treatment, design and layout

Two concentrations of $AlCl_3$ were used as treatments for the present study. They are as follows: 0 µM, 100 µM, 200 µM. The experiment was laid out in Completely Randomized Design (CRD) with three replications having two Al stress regime and five varieties. The experiment was consisted of a control, 100 µM $AlCl_3$ and 200 µM $AlCl_3$. Thus, the total number of petri dish was 45 (5×3×3) in germination experiment. The experiment was conducted in a growth chamber with normal temperature a photoperiod of 16 hours at 70% relative humidity and pH 6.0 (Rivero *et al.*, 2014).

Germination study

For observing germination capability, an experiment was setup with 45 Petri dish using filter paper and 10 seeds were placed in each Petri dish. For germination, the seeds were sterilized prior to the placement by 5–7% sodium hypochloride for 30 minutes (Custodio *et al.*, 2023). After sterilization seeds were cleaned with water and dried for 20 minutes, then again placed in water for imbibition. During the germination experiment 4–5 ml of control, 100 µM and 200 µM $AlCl_3$ was sprayed in each Petri dish at the rate of two times per day.

Collection of data

Root length: Root length of all sprouting from each replication were measured at 10, 15 and 20 DAT. Root length was measured from root base to the root tip (Wang *et al.*, 2020).

Shoot length: Shoot and root length of all sprouting from each replication were measured at 10, 15 and 20 DAT. Shoot length was measured from shoot base to the tip of the longest leaf (Chen *et al.*, 2020).

Fresh and dry weight of seedling shoot and root: Fresh weight was recorded at 5 days interval from 10 to 20 DAT. Shoot and root was measured individually as fresh weight. The data of fresh weight were computed and expressed in mg seedling^{-1} (Dass *et al.*, 2016). After measuring the fresh weight, the samples were dried in oven at 80°C for 72 hours and their weight were recorded at 10, 15 and 20 DAT.

Vigor index: Vigor index was calculated using the formula stated (Beedi *et al.*, 2018).

$$\text{Vigor Index (VI)} = \text{Seedling length} \times \text{germination}$$

Stress tolerance indices (STIs)

The Al treatments comprising of 0 μM Al (control), 100 μM Al and 200 μM Al were imposed using $AlCl_3$ to the petri dish twice in a day to confirm the wet environment for seed germination and get induced by Al stress. Apart from, stress tolerance indices of the above-mentioned parameters were also judged using formula stated (Sagar *et al.*, 2018).

$$\text{Stress Tolerance Index (STI)} = \frac{\text{Data at stress}}{\text{Data at control}} \times 100$$

Statistical analysis

Data were statistically analyzed for the analysis of variance (ANOVA) using MSTAT computer program in accordance with the principles of completely randomized design (Gomez and Gomez, 1984). Morphophysiological parameters were statistically analyzed with two factorial analyses using five varieties and three Al stress levels. In addition, stress tolerance indices of the studied parameters were statistically analyzed with two factorial analyses using five varieties and two Al stress levels compared to control treatment. Duncan's Multiple Range Test (DMRT) was used to compare variations among the treatments at 5% level of probability (Russel, 1986).

RESULTS AND DISCUSSION

Combined effect of morpho-physiological response of maize genotypes

Root length: The length of root of maize varied significantly from 28.23 to 14.70 cm among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (28.23 cm) root length in control (0 μM $AlCl_3$) growing condition. On the other hand, the variety BWMRI-1 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (14.70 cm) length of root (Table 1). Similarly, in maize, seminal root length is a biological trait that represents the Al tolerance rate with great precision and assurance (Zishiri *et al.*, 2022).

Shoot length: The length of shoot of maize varied significantly from 27.90 to 15.38 cm among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-16 showed the highest (27.90 cm) shoot length in control (0 μM $AlCl_3$) growing condition. On the other hand, the variety Kaveri-50 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (15.38 cm) length of shoot (Table 1). Similarly, the shoot length was also decreased in V_1 (23.4%) and V2 (54.2%) in non-inoculated control while in inoculated plants increase in shoot length was noted in V_1 (53.3%) and V2 (63.1%) as compared to non-inoculated plants at 30 μM Cd concentration (Tanwir *et al.*, 2021).

Seedling length: The length of seedling of maize varied significantly from 51.93 to 31.50 cm among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-16 showed the highest (51.93 cm) seedling length in control (0 μM $AlCl_3$) growing condition followed by the variety Konok in aluminium stress condition (100 μM $AlCl_3$). On the other hand, the variety BWMRI-1 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (31.50 cm) length of seedling followed by the same variety grown in (100 μM $AlCl_3$) condition (36.73 cm) in this study (Table 1).

Shoot fresh weight: The weight of fresh shoot of maize varied significantly from 4.35 to 1.79 g among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (4.35 g) shoot fresh weight in control (0 μM $AlCl_3$) growing condition followed by the same variety in aluminium stress condition (100 μM $AlCl_3$) and variety BHM-14 and BHM-16 in control (0 μM $AlCl_3$) growing condition. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (1.79 g) shoot fresh weight which was statistically identical with variety Kaveri-50 in (100 μM $AlCl_3$) condition and BWMRI-1 with aluminium stress condition (100 μM $AlCl_3$) and (200 μM $AlCl_3$) (Table 1).

Shoot dry weight: The weight of dry shoot of maize varied significantly from 0.53 to 0.20 g among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (0.53 g) shoot dry weight in control (0 μM $AlCl_3$) growing condition followed by the same variety in aluminium stress condition (100 μM $AlCl_3$). On the other hand, the variety BHM-16 and Kaveri-50 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (0.20 g) shoot dry weight (Table 1).

Root fresh weight: The weight of fresh root of maize varied significantly from 8.18 to 1.96 g among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (8.18 g) root fresh weight in control (0 μM $AlCl_3$) growing condition followed by the Kaveri-50 variety in control (0 μM $AlCl_3$) treatment. On the other hand, the variety BWMRI-1 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (1.96 g) root fresh weight which was statistically identical with BWMRI-1 in aluminium stress condition (100 μM $AlCl_3$) and BHM-14, BHM-16 in aluminium stress condition (200 μM $AlCl_3$) (Table 2). Similar phenomenon was also reported by Khan *et al.* (2019).

Table 1. Combined effect of variety and treatment on root length, shoot length, seedling length, shoot fresh weight, shoot dry weight of maize.

Variety	Treatment ($AlCl_3$)	Root length (cm)	Shoot length (cm)	Seedling Length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
Konok	0 µM	28.23 a	22.83 abc	51.07 ab	4.35 a	0.53 a
	100 µM	23.73 cd	18.67 cde	42.40 b	3.45 b	0.40 b
	200 µM	17.13 hi	17.13 de	34.27 ef	2.63 c	0.30 cde
Kaveri-50	0 µM	23.83 cd	20.63 bcd	44.47 cd	2.60 c	0.31 cd
	100 µM	21.07 ef	20.88 bcd	41.93 d	2.16 e	0.25 fgh
	200 µM	18.50 gh	15.38 e	33.87 ef	1.93 e	0.20 i
BWMRI-1	0 µM	25.17 bc	20.83 bcd	46.00 cd	2.59 cd	0.33 c
	100 µM	17.83 gh	18.90 cde	36.73 e	2.05 e	0.26 efg
	200 µM	14.70 j	16.80 de	31.50 f	1.88 e	0.21 hi
BHM-14	0 µM	22.77 de	24.70 ab	47.47 abc	3.28 b	0.30 cd
	100 µM	25.30 bc	21.30 bcd	46.60 bcd	2.68 c	0.27 def
	200 µM	26.93 ab	19.50 cde	46.43 bcd	2.18 de	0.22 ghi
BHM-16	0 µM	24.03 cd	27.90 a	51.93 a	3.29 b	0.31 cd
	100 µM	19.43 fg	22.90 abc	42.33 d	2.83 c	0.25 fgh
	200 µM	15.60 ij	18.23 cde	33.83 ef	1.79 e	0.20 i
SE (±)		1.37	0.49	1.28	0.11	0.12
CV (%)		8.27	2.83	3.73	5.22	4.97

Significant at 5% level of probability.

Table 2. Combined effect of variety and treatment on root fresh weight, root dry weight, total fresh weight, total dry weight, vigor index of maize.

Variety	Treatment ($AlCl_3$)	Root fresh weight (g)	Root dry weight (g)	Total fresh weight (g)	Total dry weight (g)	Vigor index
Konok	0 µM	8.18 a	1.21 a	12.54 a	1.74 a	5106.7 a
	100 µM	5.83 c	1.04 b	9.28 b	1.44 b	4240.0 abcd
	200 µM	3.80 ef	0.96 c	6.43 de	1.26 c	3426.7 defg
Kaveri-50	0 µM	6.54 b	1.03 bc	9.14 b	1.34 c	4446.7 abc
	100 µM	4.31 de	0.85 d	6.46 de	1.09 ef	3875.3 cdef
	200 µM	3.28 f	0.72 ef	5.21 f	0.92 g	3164.7 fg
BWMRI-1	0 µM	3.47 f	0.82 b	6.06 e	1.15 de	4134.0 bcde
	100 µM	2.54 g	0.65 g	4.60 fg	0.90 g	3299.7 efg
	200 µM	1.96 g	0.55 h	3.84 h	0.67 h	3520.0 g
BHM-14	0 µM	4.75 d	0.99 bc	80.03 c	1.30 c	4590.3 abc
	100 µM	3.57 f	0.74 e	6.26 e	1.02 f	4348.7 abcd
	200 µM	2.41 g	0.63 g	4.59 fg	0.86 g	4024.0 cdef
BHM-16	0 µM	3.80 ef	0.87 b	7.09 d	1.17 d	5020.3 ab
	100 µM	3.17 f	0.66 fg	6.00 e	0.92 g	3953.0 cdef
	200 µM	2.40 g	0.47 i	4.19 gh	0.67 i	2592.7 g
SE (±)		0.17	0.02	0.19	0.02	249.51
CV (%)		5.22	2.97	3.60	2.37	7.80

Significant at 5% level of probability.

Root dry weight: The weight of dry root of maize varied significantly from 1.21 to 0.47 g among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (1.21 g) root dry weight in control (0 µM $AlCl_3$) growing condition. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (0.47 g) root dry weight (Table 2).

Total fresh weight: The total fresh weight of maize varied significantly from 12.54 to 3.84 g among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (12.54 g) total fresh weight in control (0 µM $AlCl_3$) growing condition followed by the same variety in aluminium stress condition (100 µM $AlCl_3$) treatment. On the other hand, the variety BWMRI-1 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (3.84 g) total fresh weight (Table 2).

Total dry weight: The total dry weight of maize varied significantly from 1.74 to 0.67 g among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (1.74 g) total dry weight in control (0 µM $AlCl_3$) growing condition followed by the same variety in aluminium stress condition (100 µM $AlCl_3$) treatment. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (0.67 g) total dry weight (Table 2). The results are in agreement with the findings of Batista et al. (2013).

Vigor index: Vigor index of maize varied significantly from 5106.7 to 2592.7 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (5106.7) vigor index in control (0 µM $AlCl_3$) growing condition. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (2592.7) total dry weight which was statistically similar with variety BWMRI-1 in aluminium stress condition (200 µM $AlCl_3$) (Table 2). Shovon *et al.* (2022) also reported the similar phenomenon at 200 µM Al exposure, the germination percentage and vigor index were highest in BARI Gom-28 followed by BARI Gom-23 and lowest in BARI Gom-27.

Root length stress tolerance index: Root length stress tolerance index of maize varied significantly from 118.33 to 58.42 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-14 showed the highest (118.33) RLSTI in aluminium stress condition (200 µM $AlCl_3$) growing condition followed by same variety in aluminium stress condition (100 µM $AlCl_3$). On the other hand, the variety BWMRI-1 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (58.42) RLSTI which was statistically similar with variety Konok in aluminium stress condition (200 µM $AlCl_3$) (Table 3).

Shoot length stress tolerance index: Shoot length stress tolerance index of maize varied significantly from 101.00 to 65.39 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Kaveri-50 showed the highest (101.00) SLSTI in aluminium stress condition (100 µM $AlCl_3$) growing condition. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (65.39) SLSTI (Table 3).

Seedlings length stress tolerance index: Seedlings length stress tolerance index of maize varied significantly from 98.19 to 65.15 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-14 showed the highest (98.19) SDLSTI in aluminium stress condition (100 µM $AlCl_3$) growing condition which was statistically identical with same variety in aluminium stress condition (200 µM $AlCl_3$). On the other hand, the variety BHM-16 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (65.15) SDLSTI (Table 3).

Shoot fresh weight stress tolerance index: Shoot fresh weight stress tolerance index of maize varied significantly from 86.18 to 54.61 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-16 showed the highest (86.18) SFWSTI in aluminium stress condition (100 µM $AlCl_3$) growing condition which was statistically identical with Kaveri-50 and BHM-14 variety in aluminium stress condition (100 µM $AlCl_3$). On the other hand, the variety BHM-16 grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (54.61) SFWSTI (Table 3).

Shoot dry weight stress tolerance index: Shoot dry weight stress tolerance index of maize varied significantly from 90.14 to 56.95 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-14 showed the highest (90.14) SDWSTI in aluminium stress condition (100 µM $AlCl_3$) growing condition. On the other hand, the variety Konok grown in aluminium stress condition (200 µM $AlCl_3$) recorded the lowest (56.95) SDWSTI (Table 3).

Table 3. Combined effect of variety and treatment on root length stress tolerance index, shoot length stress tolerance index, seedling length stress tolerance index, shoot fresh weight stress tolerance index and shoot dry weight stress tolerance index of maize.

Variety	Treatment ($AlCl_3$)	Root length stress tolerance index	Shoot length stress tolerance index	Seedling length stress tolerance index	Shoot fresh weight stress tolerance index	Shoot dry weight stress tolerance index
Konok	100 µM	84.11 cd	81.73 ab	83.03 bc	79.60 ab	75.33 abcd
Konok	200 µM	60.71 g	75.08 ab	67.11 ef	60.65 cd	56.95 e
Kaveri-50	100 µM	88.36 c	101.00 a	94.39 ab	83.22 a	79.90 abc
Kaveri-50	200 µM	77.65 de	74.49 ab	76.14 cdef	74.29 abc	63.54 de
BWMRI-1	100 µM	70.92 ef	90.72 ab	79.89 cde	79.28 ab	78.19 abcd
BWMRI-1	200 µM	58.42 g	80.63 ab	68.50 def	72.43 abc	64.17 cde
BHM-14	100 µM	111.17 b	86.24 ab	98.19 a	81.80 a	90.14 a
BHM-14	200 µM	118.33 a	78.94 ab	97.82 a	66.34 bcd	73.54 bcd
BHM-16	100 µM	80.92 d	82.07 ab	81.51 bcd	86.18 a	82.64 ab
BHM-16	200 µM	64.99 fg	65.39 b	65.15 f	54.61 d	64.24 cde
SE (±)		7.73	1.98	3.70	4.10	4.52
CV (%)		2.98	11.61	5.59	6.81	7.61

Significant at 5% level of probability.

Root fresh weight stress tolerance index: Root fresh weight stress tolerance index of maize varied significantly from 83.57 to 46.53 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-16 showed the highest (83.57) RFWSTI in aluminium stress condition (100 μM $AlCl_3$) growing condition followed by variety BWMRI-1 in aluminium stress condition (100 μM $AlCl_3$). On the other hand, the variety Konok grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (46.53) RFWSTI (Table 4).

Root dry weight stress tolerance index: Root dry weight stress tolerance index of maize varied significantly from 86.26 to 54.30 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (86.26) RDWSTI in aluminium stress condition (100 μM $AlCl_3$) growing condition. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (54.30) RDWSTI (Table 4).

Total fresh weight stress tolerance index: Total fresh weight stress tolerance index of maize varied significantly from 84.76 to 51.43 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-16 showed the highest (84.76) TFWSTI in aluminium stress condition (100 μM $AlCl_3$) growing condition followed by variety Konok and BWMRI-1 in aluminium stress condition (100 μM $AlCl_3$). On the other hand, the variety Konok grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (51.43) TFWSTI (Table 4).

Total dry weight stress tolerance index: Total dry weight stress tolerance index of maize varied significantly from 82.91 to 56.84 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety Konok showed the highest (82.91) TDWSTI in aluminium stress condition (100 μM $AlCl_3$) growing condition which was statistically identical with variety Kaveri-50 in aluminium stress condition (100 μM $AlCl_3$). On the other hand, the variety BHM-16 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (56.84) TDWSTI (Table 4).

Vigor index stress tolerance index: Vigor index stress tolerance index of maize varied significantly from 95.39 to 51.63 among the effect of combination of variety and treatment. Among the treatments of combinations, the variety BHM-14 showed the highest (95.39) VISTI in aluminium stress condition (100 μM $AlCl_3$) growing condition. On the other hand, the variety BHM-16 grown in aluminium stress condition (200 μM $AlCl_3$) recorded the lowest (51.63) VISTI (Table 4).

Table 4. Combined effect of variety and treatment on root length stress tolerance index, shoot length stress tolerance index, seedling length stress tolerance index, shoot fresh weight stress tolerance index and shoot dry weight stress tolerance index of maize.

Variety	Treatment ($AlCl_3$)	Root fresh weight stress tolerance index	Root dry weight stress tolerance index	Total fresh weight stress tolerance index	Root dry weight stress tolerance index	Vigor index stress tolerance index
Konok	100 μM	71.42 bc	86.26 a	74.10 b	82.91 a	83.03 abc
Konok	200 μM	46.53 f	79.64 abc	51.43 e	72.75 bc	67.11 bcd
Kaveri-50	100 μM	65.88 bcd	82.28 ab	70.75 bc	81.70 a	87.14 ab
Kaveri-50	200 μM	50.24 ef	70.25 cde	57.08 de	68.70 c	71.14 bcd
BWMRI-1	100 μM	73.03 b	79.29 abc	75.76 b	78.84 ab	80.01 abc
BWMRI-1	200 μM	56.68 de	67.83 de	63.37 cd	66.64 c	61.34 cd
BHM-14	100 μM	75.31 ab	74.85 bcd	77.92 ab	78.43 ab	95.39 a
BHM-14	200 μM	50.76 ef	63.78 ef	57.14 de	66.08 c	87.67 ab
BHM-16	100 μM	83.57 a	76.54 abcd	84.76 a	78.12 ab	78.85 abc
BHM-16	200 μM	63.18 cd	54.30 f	59.19 d	56.84 d	51.63 d
SE (±)		2.70	2.84	2.09	2.22	6.52
CV (%)		5.20	4.74	3.82	3.72	10.47

Significant at 5% level of probability.

Conclusion

The study revealed that the variety exhibited significantly better performance under conditions without aluminum stress compared to those under aluminum stress. Consequently, the most substantial outcomes were observed in the absence of aluminum stress, specifically in the control treatment. Conversely, the lowest results were recorded in the treatment with maximum aluminum stress (200 µM AlCl3) for the experimental variety. In conclusion, the present study suggests that the maize variety "Konok" could experience greater enhancement during the early seedling stage when grown without exposure to aluminum stress.

Conflicts of interest

The authors declare no conflicts of interest regarding publication of this paper.

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