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Evaluation of Maize (*Zea mays*) Genotypes forTolerance to Drought using Yield Based Tolerance Indices

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Abstract

A pot trial was conducted at the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman University of Agriculture, Gazipur from November 2021 to March 2022 to identify relatively tolerant maize genotypes based on growth, yield, yield stability and stress tolerance. indexes. Twenty maize genotypes, including CML-580, CML-563, CML-591, CML-579, CML-588, CML-593, CML-564, BD-814, BD-821, BD-824, BD-10242, BD-811, BD-826, BD-837, BD-808, BD-10237, and BD-10240, were grown under control conditions (80% of field capacity, FC) and drought conditions (40% of FC) following completely randomized design with three replications. Plant and cob height, days to maturity, cob length, cob girth, number of rows/cob, and kernel yield/plant were recorded. Drought stress reduced plant height, cob height, cob length, cob girth, number of rows/cob, and finally maize yield, but increased the days to maturity. Among the maize genotypes, CML-593, CML-564, BD-814, and BD-821 had the lowest decrease in kernel yield, while BD-808 and BD-813 had the highest decrease. Genotypes CML-593, CML-564, BD-814, and BD-821, on the other hand, demonstrated a higher yield stability index and stress tolerance index. Based on their yield and stress tolerance index, genotypes CML-593, CML-564, BD-814, and BD-821 appear to be drought tolerant, whereas BD-808 and BD-813 appear to be drought sensitive.

Keywords: Screening; Drought tolerance; Corn; Indices.

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1. Introduction

One of the main cereal crops in the world, maize ranks third in Bangladesh behind rice and wheat in terms of cereal production. The amount of maize produced in Bangladesh in 2020 is 4,700,000 tons. Between 2011 and 2020, Bangladesh's maize production increased significantly from 1,954 to 4,700,000 tons at an annual rate of increase, peaking in 2019 at 17.14 before falling to 14.63% in 2020 [1]. In comparison to regions without a drought, maize production dropped by 22.4% in drought-stricken areas. In Bangladesh, the drought's most significant impacts included a 70% decrease in maize yield, a 55% reduction in plant growth, and a 43% difficulty with the flowering stage [2].

Drought is a global issue that poses a threat to the development of arable field crops and, ultimately, food security [3-6]. Since drought is a major abiotic stress that limits the development and productivity of crop plants, researchers have recently begun to pay more attention to the phenomenon [7-9]. Crop management methods can be improved, agricultural breeding efforts can be focused, and the future of natural vegetation in times of climate change can be predicted by knowing how drought affects plants [10]. Several genes with cumulative effects regulatedrought tolerance. Furthermore, genes controlling plant yield potential and drought tolerance interact to limit progress in drought tolerance in plants [7]. In order to find plant genotypes that are better suited for drought tolerance, more study is required.

Maize germplasms have a variety of characteristics that allow some accessions to cope with drought stress more effectively [11]. The development of climate resilient crop varieties is an option, but it may take longer period. As a result, the existing level of tolerance in available germplasms can be determined [12] and utilized through evaluation under artificial stress conditions. According to Gayosso-Barragán [13], the genetic parameter estimation revealed data on the population's genetic variation and heritability, which is crucial for the advancement of the selection process.

Many indices have been developed to assess stress and stress tolerance. These are both physiological and agronomic indicators. Several selection indices, mostly based entirely on formulas, have been proposed for selecting drought-tolerant genotypes by assessing their overall performance under stress and well-water conditions [3, 14-17]. Decrease in seed yield under stressful conditions compared to yield under well water conditions is primarily a measure of genotypic drought susceptibility comparison [14, 18]. The Yield Stability Index (YSI) is an index proposed by Bouslama and Schapaugh [19] to assess the stress tolerance of soybeans [Glycine max(L.) Merr.]. Fernandez [14] defined a stress tolerance index (STI) to distinguish between genotypes with high yield potential and high stress tolerance. Therefore, this study planned to identify potential genotypes of water stress and well water conditions by comparing two drought tolerance indices and knowing the association between these indices and grain yield. Therefore, an attempt was made to identify suitable drought-tolerant maize genotypes using two indicators (YSI and STI) that are generally of agronomic nature.

2. Materials and Methods

2.1. Experimental Site and Soil

The experiment was set up into a semi-controlled environment (inside screenhouse) at the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh during November 2021 to March 2022. The geographical location of the experimental site is 24.09^{o} N latitude and 90.26^{o} E longitude at 8.4 m higher than the sea level. The day and night temperatures were 28.5 ± 1.6 and 13.6 ± 1.3°C between the screenhouse. Sandy loam with a field capacity of 28% and a pH of 6.93 made up the employed soil throughout the profile (54.21% sand, 34.60% silt, and 11.19% clay). The soil's organic carbon content, available phosphorus (P), total nitrogen (N), exchangeable potassium (K), cation exchange capacity (CEC), and electrical conductivity (EC) values were 0.61%, 0.06 mg/100 g, 0.07%, 0.79 cmoles / kg of dry soil, 13.05 cmoles / kg of dry soil, and 0.04 dS / m, respectively [9].

The soil (the mixture of soil and cow dung at a ratio of 4:1) used in the experiment holds about 28% moisture at field capacity (FC). The each pot (30 cm x 11 cm) was filled up with 11 kg of air-dried mixture of soil. The recommended fertilizers were applied with 1.872 g urea, 1.30 g TSP, 0.86 g MoP, 1.008 g Zypsum, 0.090 g ZnSO4 and 0.042 g boric acid /pot corresponding to 312 kg urea, 216 kg TSP, 144 kg MoP, 168 kg Zypsum, 15 kg ZnSO4 and 7 kg boric acid /ha, respectively [20].

2.2. Experimental Factors and Design

The experiment was comprised of two factors; a) 20 maize genotypes and b) 2 water regimes: control (80% of FC) and drought stress (40% of FC). List of genotypes with their collectiong sources are presented in Table 1. These 20 maize genotypes were screened out from 97 exotic and native genotypes at germination and vegetative stages against drought stress.

Table-1. List of genotypes used in the experiment

Sl No	Name of genotype	Source	Sl No.	Name of genotype	Source
1.	CML-580	CIMMYT, Mexico	11.	BD-814	Bangladesh Agricultural Research Institute
2.	CML-563	CIMMYT, Mexico	12.	BD-821	Bangladesh Agricultural Research Institute
3.	CML-591	CIMMYT, Mexico	13.	BD-827	Bangladesh Agricultural Research Institute
4.	CML-579	CIMMYT, Mexico	14.	BD-813	Bangladesh Agricultural Research Institute
5.	CML-588	CIMMYT, Mexico	15.	BD-812	Bangladesh Agricultural Research Institute
6.	CML-593	CIMMYT, Mexico	16.	BD-824	Bangladesh Agricultural Research Institute
7.	CML-564	CIMMYT, Mexico	17.	BD-10242	Bangladesh Agricultural Research Institute
8	BD-827	Bangladesh Agricultural Research Institute	18.	BD-811	Bangladesh Agricultural Research Institute
9.	BD-813	Bangladesh Agricultural Research Institute	19.	BD-826	Bangladesh Agricultural Research Institute
10.	BD-812	Bangladesh Agricultural Research Institute	20.	BD-826	Bangladesh Agricultural Research Institute

Seeds of 20 maize genotypes were sown on November 08, 2021. The crops were grown following the standard cultivation techniques [21] and the experiment was laid out in a Completely Randomized Design (CRD) with 3 replications. Drought stress was imposed through withdran of irrigation after germination. In control trated and in drought pots pots 80% of FC and 40% of FC were maintained, respectively throughout the growing season. The moisture level in each pots was monitored by using portable digital moisture meter (POGO Soil Sensor II, Stevens, USA) and required amount of was was applied.

2.3. Data Collection

Plant height, cob height from soil, days to maturity, cob length, cob girth, number of rows/cob, and kernel yield/plant were all measured on both the control and drought-stressed plants. The yield stability index and the stress tolerance index of maize genotypes were calculated using the following formula:

Index	Formula	Reference
Yield Stability Index	YSI=Ys/Yp	[20]
Stress Tolerance Index	STI=(Yp*Ys)/ (Ỹp)2	[19]

Yp and Ys: Karnel yield of each studied genotype under control (80% of FC) and drought stress conditions (40% of FC), respectively.

Ỹp and Ỹs: Average karnel yield of all used genotypes under control and drought stress conditions, respectively

2.4. Statistical Analysis

The collected data of all parameters were statistically analyzed using CropStat 7.2 and MS office Excel programs.

3. Results and Discussion

3.1. Plant Height

Growth of maize plant negatively impacted by drought. The tallest plant was observed under control condition and the shortest plant was measured at drought stress condition (Table 2). For cell division and cell enlargement, water is required for which was more readily available at control situation, whereas soils under drought could not provide an adequate amount of water for apical growth. As a result, at drought condition, plant height was reduced. At 80% of FC, maize genotype BD-812 produced the greatest height (185.33 cm). Under drought, the highest relative (% of control) plant height was observed in genotype BD-814 (80% of control), followed by CML-593 (76% of control), CML-580 (76% of control), while genotype BD-10237 produced the least height of 51 cm (42% of control). Drought is one of the major abiotic stresses that are influenced by irrigular rainfall patterns rather than other abiotic stresses such as excessive salt stress, waterlogging, and specific ion toxicity. In our study we have found, the interaction between maize genotypes and drought was quite significant. There was a noticeable difference in plant height between the best performing maize genotype BD-814 and the other genotypes. This could be attributed to a lack of water for photosynthesis, which ultimately decreased the growth. Furthermore, it could be attributed to less soil absorption of water and nutrients. Olaoye, *et al.* [22] confirmed these findings, reporting those 24 days after sowing, 100% of FC increased plant height of maize hybrids up to 45.38 cm and decreasing FC decreased plant height. According to Sah and Zamora [23], water deficit stress significantly reduces height of plant during the vegetative stage. Water scarcity slowed down growth of plant by altering the growth pattern and development to a significant extent.

3.2. Cob Height

The highest cob height from soil was found at the control (80% of FC), and the lowest at drought condition (Table 2). At drought condition, the cob's height was reduced. Maize genotype BD-812 produced the greatest height, with an FC of 80% (98.33 cm). At 50% of FC, the genotypes CML-591 produced the highest relative cob height (82% of control), while genotype BD-10237 produced the lowest relative cob height (38% of control). In terms of cob height from the soil, the genotype CML-591 showed the best performance from the other genotypes. A large number of pollen grains for fertilization received by the ear if height of ear is medium and reduces the incidence of animal damage and there was a positive correlation with grain yield and cob height [24] which was supported by our results.

Table-2. Effect of drought on plant height, cob height, and days to maturity of selected maize genotypes

Genotypes	Plant height (cm)		Cob height (cm)		Days to maturity	
	Control	Drought	Control	Drought	Control	Drought
BD-827	156.67	96.67 (62)	82.30	50.00 (61)	121.17	126.50 (104)
BD-813	147.33	93.67 (64)	75.33	40.00 (53)	116	122.67 (106)
BD-812	185.33	114.00 (62)	98.33	56.33 (57)	118.67	125.33 (106)
CML-580	121.34	91.66 (76)	54.66	40.30 (74)	121.33	130.33 (107)
CML-563	119.67	83.00 (69)	57.32	43.67 (76)	123	131.33 (107)
CML-591	117.00	85.66 (73)	57.66	47.32 (82)	130.33	131.33 (101)
CML-579	113.30	82.67 (73)	55.00	41.33 (75)	126.5	130 (103)
CML-588	146.00	101.00 (69)	67.67	51.66 (76)	119.33	128.83 (108)
CML-593	103.00	78.32 (76)	51.00	35.67 (70)	132.83	130.67 (98)
CML-564	103.33	71.33 (69)	55.33	33.66 (61)	120	128.67 (107)
BD-814	105.67	84.30 (80)	57.33	32.00 (56)	118	128.17 (109)
BD-821	153.67	94.34 (61)	75.60	45.00 (60)	119.33	123.67 (104)
BD-824	152.00	79.66 (52)	78.33	43.66 (56)	120	122.67 (102)
BD-10242	155.33	98.30 (63)	85.33	49.30 (58)	126.33	126 (100)
BD-811	142.60	75.33 (53)	80.00	43.67 (55)	115	124 (108)
BD-826	151.00	83.00 (55)	81.32	53.00 (65)	115	123 (107)
BD-10240	144.00	84.00 (58)	70.66	49.00 (69)	121.17	126.33 (104)
BD-808	121.32	82.30 (68)	63.00	41.67 (66)	115.83	120 (104)
BD-10237	120.00	51.00 (42)	22.33	8.54 (38)	125	126 (101)
BD-837	153.00	96.00 (63)	74.00	45.00	130	126.83 (98)
LSD (5%)	21.81		16.04		5.44	
CV (%)	12.1		17.9		2.7	

Values in the parenthesis indicates % of control

3.3. Days to Maturity

The genotypes' days to maturity differ between control and drought situations (Table 2). The majority of the genotypes were shown to require more days to mature in drought conditions than in control condition; however two genotypes showed an exception. At control condition, the genotype CML-593 took the most days to reach maturity (132.83 days), followed by CML-591 (130.33 days), and BD-837 (130 days), but genotypes BD-811 and BD-826 required the fewest days to reach maturity (115 days of each). At 50% FC, CML-591 and CML-563 had the longest days to maturity (131.33 days for each), followed by CML-593 (130.67 days) and CML-580 (130.33 days), whereas genotype BD-808 had the fewest days to maturity (120 days). According to Anjum, *et al.* [25], to avoid environmental stress effects, some plants complete their life cycle earlier to normal condition, which is consistent with our findings. It is the time takes from seed set to physiological maturity is known as grain filling duration. It is well known that drought stress reduces seed yield. The obvious effects include a shorter seed filling period, which reduces final seed size [26]. If water deficit occurred during the seed maturing period, it may result in a decrease in the number of seeds. Surprisingly, a short seed filling period is a versatile characteristic in plant species exposed to water deficit stress [27].

3.4 Cob Length

There was a negative impact of drought on cob growth. The longest cob was recorded at control and the shortest was recorded at drought condition (Table 3). At 50% of FC, cob length was reduced. At 80% of FC, maize genotype BD-837 produced the greatest length of cob (16.17 cm) followed by BD-827 (15.33 cm), BD-10240 (15 cm), BD-10237 (13 cm), BD-812 (12.83 cm) and the shortest cob length was recorded in genotype BD-826 (8.5 cm). At 50% FC, the relative cob length was highest in genotypes CML-564 (95% of control), followed by BD-814 (94% of control), CML-593 (92% of control), CML-580 (86% of control), CML-579 (77% of control). On the other hand, the relative cob length was the shortest in genotype BD-813 (35% of control). Longer cobs improve other important yield factors such as increased total grains per cob and fresh weight [28, 29]. The minimum cob length obtained from genotype BD-813 due to drought stress during the vegetative phase is consistent with similar results of cob length reduction when maize plants were exposed to drought during his 5-leaf stage reportrd by Zamir, *et al.* [30]. However, under drought condition at all growth stages exhibit significantly shorter ear lengths among all plants studied. The longest ear under drought condition in genotype CML-564 indicated that this genotype is relatively drought tolerant compared to the other genotypes examined.

3.5. Cob Girth

To determine crop yield potentiality, the cob girth is an important consideration. Drought stress has been shown to affect corn yield components such as girth. There was a significant variation in cob girth produced by different genotypes in our study (Table 3). At control condition, the highest cob girth was recorded in genotype CML-593 (14.67 cm), which was followed by BD-821 (14 cm), CML-564 (13 cm), BD-808 (12.67 cm) and the lowest cob girth was produced by genotype CML-591 (9.5 cm). At 50% FC, the highest relative cob girth was recorded in genotype CML-593 (86% of control), followed by CML-564 (85% of control), BD-814 (84% of control), CML-579 (82% of control) and the lowest relative cob girth was observed in BD-813 (46% of control). According to Akir [31] as well as Khodarahmpour and Hamidi [32], higher cob girth is frequently connected with higher kernel row numbers, cob diameter, grain number, and total cob size. In our study it was found a correlation between the rise in CML-593 cob girth and other yield components such the quantity of grains, longer cob length, and greater fresh weight following harvest.

3.6. Number of Rows/Cob

Genotypic variation was observed in the yield parameter number of rows/cob. At control, the highest number of rows/cob was found in genotype 814 (15.33), followed by CML-593 (15),

Table-3. Effect of drought on cob length, cob diameter, number of kernel/row and yield of selected maize genotypes

Genotypes	Cob length (cm)		Cob girth (cm)		Number of row/cob		Kernel yield/plant	
	Control	Drought	Control	Drought	Control	Drought	Control	Drought
BD-827	15.33	9.33 (61)	10.67	5.70 (53)	12	7 (58)	40.51	13.22 (33)
BD-813	12.33	4.33 (35)	11.17	5.17 (46)	14	6.67 (48)	52.15	8 (15)
BD-812	12.83	8 (62)	11	8.33 (76)	13.83	10.23 (73)	53.01	23.47 (44)
CML-580	9.33	8 (86)	11	8.33 (76)	12	10 (83)	36.26	20.32 (56)
CML-563	12.67	6 (47)	12	8 (67)	10	6.67 (67)	26.90	10.49 (39)
CML-591	10.67	7 (66)	9.5	6 (63)	12	6.33 (53)	28.71	11.27 (39)
CML-579	8.17	6.33 (77)	11	9 (82)	10	8.67 (87)	43.02	23.43 (54)
CML-588	9.66	5.83 (60)	10.67	8.33 (78)	12.33	8.67 (70)	31.97	13.18 (41)
CML-593	12	11 (92)	14.67	12.67 (86)	15	14.33 (96)	52.35	38.41 (73)
CML-564	11	10.5 (95)	13	11 (85)	11.33	10 (88)	51.13	36.32 (71)
BD-814	7.83	7.33 (94)	10.33	8.67 (84)	15.33	14 (91)	53.39	35.79 (67)
BD-821	11.67	8 (68)	14	11 (79)	10.67	9.33 (87)	37.91	22.44 (59)
BD-824	12.33	7.33 (59)	11	5.50 (50)	12.67	6.67 (53)	34.68	9.99 (29)
BD-10242	9.67	6 (62)	11.33	9.33 (82)	14	10.33 (74)	30.48	13.80 (45)

BD-811	9.17	6 (65)	11.33	8 (71)	12.67	9 (71)	35.33	18.56 (53)
BD-826	8.5	6.27 (74)	11.67	9.33 (80)	14	11.67 (83)	40.47	21.77 (54)
BD-10240	15	8 (53)	10.67	6 (56)	12.33	8 (65)	41.96	21.84 (52)
BD-808	13	6 (46)	12.67	6 (47)	14.67	4.17 (28)	68.01	11.67 (17)
BD-10237	13	7 (54)	11	7.67 (70)	13.33	6 (45)	25	10.33 (41)
BD-837	16.17	11.67 (72)	11.50	8.33 (72)	13.67	10 (73)	64.75	34.29 (53)
LSD (5%)	2.21		1.70		2.68		11.86	
CV (%)	14.2		10.7		14.8		13.4	

Values in the parenthesis indicates % of control

BD-808 (14.67) and the lowest number of rows/cob were obtained from genotype CML-563 (10). At 50% FC, the relative number of rows/cob was maximum in genotype CML-593 (96% of control), followed by BD-814 (91% of control), CML-564 (88% of control), CML-579 (87% of control) but the minimum relative number of rows/cob was found in genotype BD-808 (28% of control) (Table 3). Our results are supported by Sah, *et al.* [24] where they observed number of rows/cob reduced up to 29.69% in corn due to drought and lower reduction were observed in tolerant genotypes..

3.7. Kernel Yield/Plant

There was a statistical difference among the genotypes in relation to yield of maize under control and drought conditions. The highest yield was recorded from genotype BD-808 (68.01 g/plant) under control condition, which was followed by BD-837 (64.75 g), BD-814 (53.39 g) and the minimum yield was recorded in the genotype BD-10237 (25 g/plant) (Table 3). On the other hand at 50% of FC, the genotype CML-593 produced the highest relative yield of kernel/plant (73% of control), followed by CML-564 (71% of control), BD-814 (64% of control), BD-821 (59% of control) and the lowest relative yield was found in genotype BD-813 (15% of control). According to reports, the drought had an impact on yield and its constituent parts in addition to plant development itself [33]. Grain yield decreases during droughts ranged from 10 to 76%, depending on the degree of water stress and the growth stage during which the stress had occurred reported by Bolaòos, *et al.* [34] as well as Khodarahmpour and Hamidi [32]. When compared to normal and less severe drought circumstances, corn grain production under severe drought was reported to be considerably lower [35]. This was consistent with the low average number of grains that were observed in plants at 25% and 50% of FC. The number of rows per cob, length of cobs, cob diameter, grain breadth, and grain depth all had an impact on the quantity of grains per cob [32]. These findings, which show that the lower kernel yield among the genotypes under study ranged from 27 to 85%, are consistent with our findings. The genotypes CML-593, CML-564, BD-814, and BD-821 showed fewer declines, indicating that they are more resistant to drought. On the other hand, the highest reduction of yield of genotype BD-813, indicating that this genotype is vulnerable to drought.

3.8. Correlation Among Yield and Yield Contributing Characters

Significant and positive correlations were observed with yield among the plant height, cob height, cob length, cob diameter, number of row/cob (Table 4) and significantly negative correlation with days to maturity was found. There was a significant and positive correlation among plant height and cob height, cob girth, number of rows/cob and yield but the correlation was negative with days to maturity. The highest correlation ($r2 = 0.874$) was calculated between plant height and cob height. Correlation between cob height and cob length, cob girth, number of rows/cob and yield was positive on the other handsignificant but negative correlation was observed with days to maturity. A negative and non-significant correlation was observed between days to maturity and cob length, cob girth, number of rows/cob and kernel yield. There was a significantly positive correlation between cob length and cob girth, number of rows/cob and yield of maize under drought condition.

Table-4. Correlation coefficient among maize yield under control and water deficit condition and different yield contributing parameters

Parameters	Plant height	Cob height	Days to maturity	Cob length	Cob girth	Number of rows/cob	Yield/plant
Plant height	1.000						
Cob height	0.874**	1.000					
Days to maturity	0.434**	0.451**	1.000				
Cob length	0.563**	0.404**	-0.174^{NS}	1.000			
Cob girth	0.482**	0.371**	-0.190^{NS}	0.546**	1.000		
Number of rows/cob	0.503**	0.415**	-0.224^{NS}	0.411**	0.548**	1.000	
Yield/plant	0.530**	0.482**	-0.269**	0.606**	0.679**	0.677**	1.000

NS= non-significant, ** 1% level of significance, respectively.

3.9. Yield Stability Index and Stress Tolerance Index

Yield capacity of the genotypes under drought vs. control conditions was represented by the yield stability index of drought stressed crops. Genotype CML-593 showed the highest yield stability index (0.73), followed by CML-564 (0.71), BD-821 (0.67), and the lowest was BD-813 (0.15). (Figure 1). The CML-593 genotype showed the highest stress tolerance index (1.12), followed by the BD-814 (1.06), CML-564 (1.03) and BD-837 (1.02) but the genotype BD-10237 showed the lowest stress tolerance index (0.14) (Fig. 2.

Fig-1. Yield stability index of maize genotypes

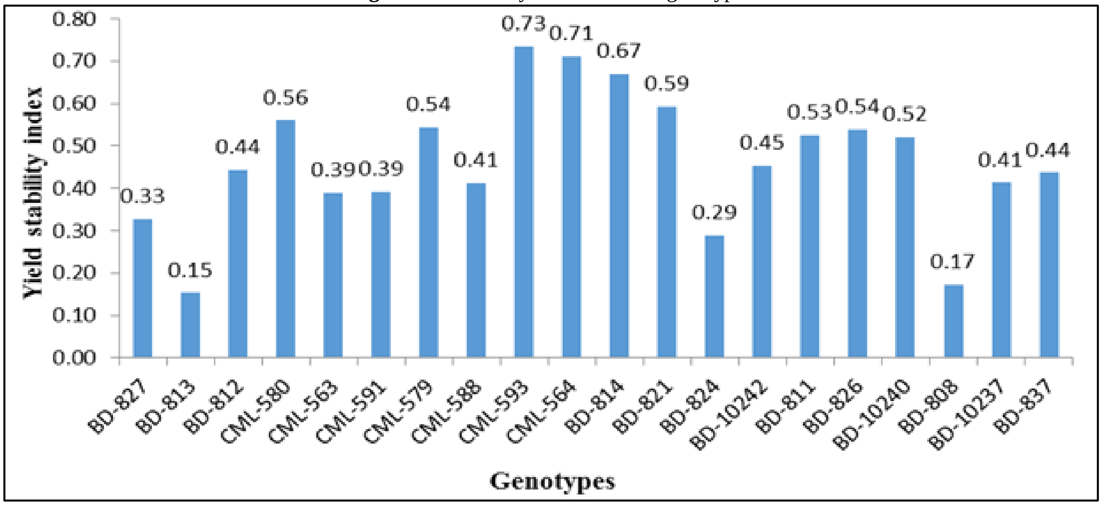
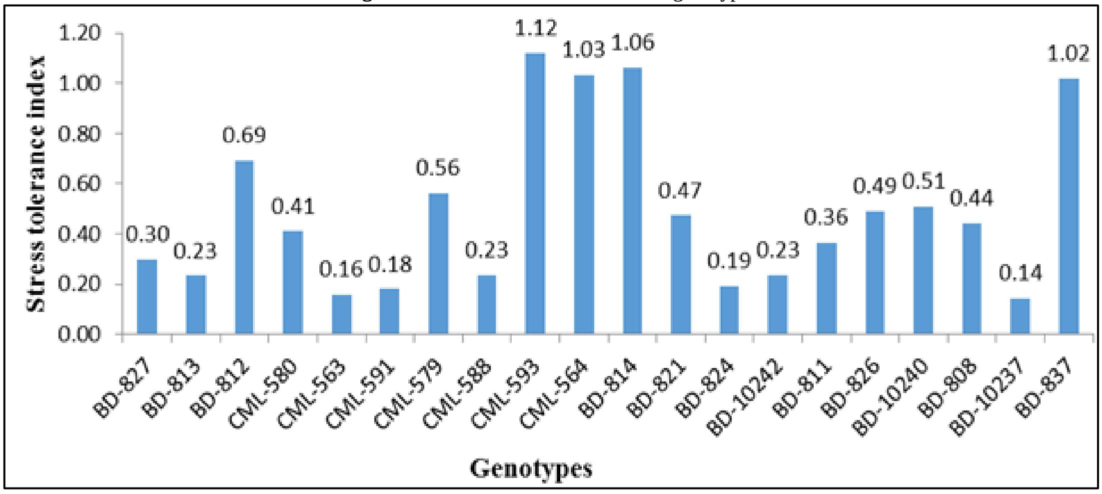


Fig-2. Stress tolerance index of maize genotypes



4. Conclusions

From the results of the experiment, it can be stated that there was a positive and significant correlations between length of cob and girth of cob, number of rows/cob, and yield of maize under drought conditions. Higher yield stability index and stress tolerance index were observed in genotypes CML-593, CML-564, BD-814, and BD-821; on the other hand these were lower for BD-808 and BD-813. In accordance with their yield and stress tolerance index, genotypes CML-593, CML-564, BD-814, and BD-821 appear to be drought tolerant, whereas BD-808 and BD-813 appear to be drought sensitive.

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Authors Contributions

Md. Abdul Mannan and Ferdousi Begum planned and carried out the research. Md Ahsan Habib carried out the experiment. Md. Abdul Mannan wrote the manuscript.Md. Abdullah Al Mamun contributed to data analysis and proof reading.

Ethics

No ethical issues may arise after the publication of this manuscript.

Conflict of interest

The authors declared no conflict of interest of this research work.

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