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Evaluation of highland maize (*Zea mays* L.) cultivars for polyethylene glycol (PEG) induced moisture stress tolerance at germination and seedling growth stages

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A laboratory experiment was performed at Ambo University, Department of Plant Sciences in March 2014, to evaluate the effect of moisture stress on germination and seedling growths of highland maize cultivars. The experiment was arranged factorially in completely randomized design with three replications. Five highland maize cultivars (Hora, Wenchi, Jibat, Argene and Wabi) were exposed to six levels of water stress (0, 60, 120, 180, 240 and 300 g/L Polyethylene glycol 6000). The result revealed that no significant interactions exist between maize cultivars and moisture stress. However, cultivars varied significantly for germination percentage and rate, shoot and root lengths, root number, and shoot and root fresh weight. Increase in PEG 6000 concentrations decreased germination percentage and rate, where as shoot and root lengths decreased beyond 60 g/l. No significant differences were observed among 60, 120 and 180 g/L for shoot and root fresh and dry weights, and seedling fresh and dry weights. Maximum root number, root-to-shoot ratio and tolerance index was observed at 120 and 180, 240 and 60 g/L PEG, respectively. Hence, highland maize cultivars showed differential response in terms of germination and seedling growth with increased moisture stress, and increase in PEG 6000 reduced germination and seedling growth beyond 60 g/L.

Key words: Germination, maize, seedling growth, stress, tolerance.

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop in terms of acreage, production, yield, distribution and adaptation in Ethiopia. Estimates of annual maize productivity per hectare reach 22 quintals, and the area coverage is 1.77 million hectares (CSA, 2011) occupying first place in total grain production and yield per hectare; although the national average yield is below the world average. The causes for low productivity of maize are abiotic and biotic constraints. Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Bayoumi et al., 2008). The causes for low productivity of maize are abiotic and biotic constraints. Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most

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major crop plants by more than 50% (Bayoumi et al., 2008). The causes for low productivity of maize are abiotic and biotic constraints. Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Bayoumi et al., 2008) which are widespread problems around the world (Soltani et al., 2006). Water stress results in reduced plant growth and yield by affecting almost every developmental stage of the plant. However, damaging effects of moisture stress was more pronounced when it coincided with various phenophases such as germination; seedling stage and flowering (Khayatnezhad et al., 2010).

Field experiments related to water stress have been difficult to handle due to significant environmental or drought interactions with other abiotic stresses (Rauf, 2008). Establishing conditions of drought stress using different osmotic materials to create the osmotic potential is considered as one of the best methods to study the effects of moisture stress on germination. Hence, an alternative approach is to induce water stress through polyethylene glycol (PEG) solutions for screening the germplasm (Khodarahmpour, 2011; Rajendran et al., 2011). Water sensitive stages may be exploited to discriminate genotypes on the basis of their resistance to water stress. Among these critical stages, water stress induced during seedling stage has been exploited in various crop species to screen germplasm or breeders populations (Bibi et al., 2012; Khayatnezhad, 2010). The current study was therefore made to evaluate the effect of moisture stress on germination and seedling growth of highland maize cultivars.

MATERIALS AND METHODS

Laboratory experiment was conducted in the Department of Plant Sciences, Ambo University, Ethiopia, to evaluate moisture stress effect on germination and seedling growth of maize cultivars. The experiment was arranged factorially in a completely randomized design with three replications. Five highland maize cultivars (Hora,Wenchi, Jibat, Argene and Wabi) were exposed to six levels of water stress (0, 60, 120, 180, 240 and 300 g/L PEG 6000) in the experiment, de-ionized water was used for the control treatment. Polyethylene glycol solution (PEG 6000) was dissolved with the respective treatment amount at 25°C with deionized water. Seeds treated with fungicides were used in the experiment. Ten seeds were uniformly placed on Watman filter paper in the Petri dish (9.5 cm diameter) using a forceps for each treatment, and well soaked by adding 22 ml of the respective solutions. All the Petri dishes were covered with lids and kept at room temperature (22 ± 2°C). Germination continued for 10 days, and germinated seeds were counted daily. The emergence of 2 mm radical was the criteria of germination. After 10 days, parameters such as percent germination and rate of germination were calculated according to ISTA (1999); and root and shoot lengths of seedling were measured using a scale. Root and shoot dry weights were recorded after oven drying for 24 h at 80°C. The seedling tolerance index (STI) was determined based on the methods described by Iqbal and Rahmati (1992).

Statistical analysis of the data was performed employing One-Way ANOVA using SAS statistical software (Version 9). Based on the ANOVA results, mean separations were performed by Duncan's multiple range test at 5% level.

RESULTS AND DISCUSSION

Germination, and shoot and root lengths

The analysis of variance indicated no significant interaction between maize cultivars and moisture stresses. However, cultivars varied significantly for germination percentage and rate. Jibate cultivar gave maximum germination percentage (92.5%), while Hora resulted in high germination rate (1.91 plants/day). Nevertheless, no significant difference was observed between Hora, Wenchi and Jibat in germination percentage and rate (Table 1). The lowest germination percentage (76.9%) and rate (1.55 plants/day) was recorded in Wabi cultivar. This finding is in agreement with the trends of Almaghrabi (2012) findings, who observed significant differences in response to drought stress on germination of wheat cultivars.

Moisture stress significantly influenced not only germination percentage and rate, but also shoot and root lengths. Germination percentage and rate were highest in control treatment and tended to decrease as the moisture stress increased using PEG (Table 2). Reduction in germination with moisture stress is attributed to lower infusibility of water through the seed coat and initial water imbibition of the seed under stress condition (Bahrami et al., 2012) and decreased external water potential. Decrease in seed germination under water stress condition could also be due to metabolic disorders such as slow hydrolysis of substrate compounds in endosperm or cotyledons and/or slower transportation of hydrolyzed material to developing embryo axis (Ayaz et al., 2000). Maximum shoot and root lengths were recorded at 60 g/L PEG stress level, but further increase in PEG concentration decreased shoot and root lengths significantly. Ghajari and Zeinali (2003) also observed an increase in shoot and radicle lengths until -0.2 MPa when using PEG-6000. Similar results also have been reported by Boureima et al. (2011) who stated that root length increased by 19.94% at -0.5 MPa in comparison with controls. Moderate drought stress increased root lengths of pearl millet cultivars by 15.8% (Radhouane, 2008). The development of the root system in response to water deficit suggests that the expression of certain genes controlling root formation is stimulated by drought conditions (Badiow et al., 2004). However, the reduction of radicle length due to excess exposure for moisture stress could be due to a cessation in cellular division and elongation at root level.

Shoot and root fresh and dry weights

The results of the study revealed that maize cultivars differed significantly in shoot and root fresh weights.

Table 1. Germination, and shoot and root lengths of maize cultivars as influenced by moisture stress.

Cultivar	Germination (%)	Germination rate (Plant/day)	Shoot length (cm)	Root length (cm)
Hora	87.2^{ab}	1.91^{a}	4.10 (2.795)^{a}	10.69 (4.14)^{ab}
Wenchi	87.8^{ab}	1.65^{ab}	3.84 (2.788)^{ab}	10.84 (4.18)^{ab}
Jibat	92.5^{a}	1.78^{ab}	3.70 (2.785)^{ab}	9.92 (4.04)^{b}
Wabi	76.9c	1.55^{b}	3.45 (2.715)^{ab}	11.28 (4.23)^{a}
Argene	83.3^{b}c	1.59^{b}	3.29 (2.632)^{b}	10.11 (4.06)^{ab}
SEm(±)	2.03	0.087	0.084	0.094
CV (%)	11.9	24	11.6	6.1

Means with similar letters in each column are not significant at 5% level of probability. Data in parenthesis are square root transformed data.

Table 2. Effect of moisture stress on germination, and shoot and root length of maize.

Moisture stress [PEG 6000 conc. (g/L)]	Germination (%)	Germination rate (Plant/day)	Shoot length (cm)	Root length (cm)
0	99.3^{a}	2.79^{a}	5.61 (3.35)^{ab}	14.14 (4.75)^{b}
60	96.7^{ab}	2.24^{b}	6.28 (3.50)^{a}	15.27(4.90)^{a}
120	96 ^{ab}	1.95^{b}	5.06 (3.23)^{b}	13.73 (4.70)^{b}
180	90.7^{b}	1.52^{c}	3.64 (2.90)^{c}	12.33(4.51) ^{c}
240	79.3^{c}	1.03^{d}	0.98 (1.94)^{d}	4.99 (3.22)^{d}
300	53.3^{d}	0.67^{e}	0.49 (1.54)^{d}	2.97(2.70)^{d}
SEm(±)	2.03	0.087	0.084	0.094
CV (%)	11.9	24	11.6	6.1

Means with similar letters in each column are not significant at 5% level of probability. Data in parenthesis are square root transformed data.

Table 3. Effect of moisture stress on shoot and root fresh and dry weights of maize cultivars.

Cultivars	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Seedling fresh weight (g)	Seedling dry weight (g)
Hora	0.116 (1.30)^{b}	0.159 (1.37)^{ab}	0.0279 (1.161)^{a}	0.051 (1.217)^{a}	0.269 (1.477) ^{a}	0.0789 (1.263)^{a}
Wenchi	0.168 (1.37)^{a}	0.164 (1.38)^{ab}	0.0321 (1.167)^{a}	0.059 (1.22)^{a}	0.332 (1.540) ^{a}	0.0914 (1.281)^{a}
Jibat	0.122 (1.32)^{ab}	0.151 (1.36)^{b}	0.0263 (1.152)^{a}	0.0419 (1.183)^{a}	0.273 (1.486) ^{a}	0.682 (1.242)^{a}
Wabi	0.139 (1.35)^{ab}	0.150 (1.36)^{b}	0.0270 (1.159)^{a}	0.0467 (1.189)^{a}	0.289 (1.505) ^{a}	0.0737 (1.252)^{a}
Argene	0.134 (1.33)^{ab}	0.197 (142)^{a}	0.0269 (1.158)^{a}	0. 0633 (1.225) ^{a}	0.331 (1.539) ^{a}	0.0902 (1.273)^{a}
SEm(±)	0.016	0.015	0.007	0.011	0.021	0.012
CV (%)	6.3	5.2	3.0	6.0	6	4.9

Means with similar letters in each column are not significant at 5% level of probability. Data in parenthesis are square root transformed data.

Similarly, Bibi et al. (2012) reported that drought has drastically affected fresh shoot and root weight in some cultivars of sorghum, wheat, maize and sunflower. However, shoot and root dry weights, and seedling fresh and dry weights of maize cultivars were not significantly different (Table 3). Cultivar Wenchi showed maximum shoot, root and seedling fresh and dry weights. Results of the current study in relation to the existence of variability among cultivars were in agreement with other experiments in chickpea (Kalefetoglu et al., 2009) and in wheat (Almansouri et al., 2001; Soltani et al., 2006).

Moisture stress levels induced by PEG 6000 concentrations significantly decreased shoot, root and seedling fresh and dry weights as PEG levels increased beyond 120 g/L (Table 4). Positive increment was observed on fresh and dry weights up to 120 g/L PEG levels. However, no significant differences were observed between 60 and 120 g/L treatments. An increase in fresh

Table 4. Effect of moisture stress induced by PEG on shoot and root fresh and dry weights of maize.

PEG 6000 Conc. (g/L)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Seedling fresh weight (g)	Seedling dry weight (g)
0	0.162 (1.378)[b]	0.111(1.32)[b]	0.0367(1.190)[b]	0.0454 (1.21)[b]	0.273 (1.50)[b]	0.082(1.28)[b]
60	0.221 (1.462)[a]	0.23 (1.47)[a]	0.0468 (1.215)[a]	0.0718 (1.26)[a]	0.45 (1.66)[a]	0.119 (1.34)[a]
120	0.2 (1.447)[a]	0.279 (1.53)[a]	0.0369 (1.192)[ab]	0.0922 (1.30)[a]	0.48 (1.69)[a]	0.129 (1.36)[a]
180	0.173 (1.413)[ab]	0.249 (1.49)[a]	0.0312 (1.175)[ab]	0.0788 (1.25)[a]	0.422 (1.64)[a]	0.11(1.32)[a]
240	0.04 (1.189)[c]	0.077 (1.27)[b]	0.0135 (1.106)[c]	0.0192 (1.13)[c]	0.116 (1.34)[c]	0.033 (1.18)[c]
300	0.023(1.123)[d]	0.031(1.17)[c]	0.0068 (1.066)[c]	0.0075 (1.08)[c]	0.054 (1.22)[c]	0.014 (1.11)[c]
SEm(±)	0.016	0.015	0.007	0.011	0.021	0.012
CV (%)	6.3	5.2	3.0	6.0	6.0	4.9

Means with similar letters in each column are not significant at 5% level of probability. Data in parenthesis are square root transformed data.

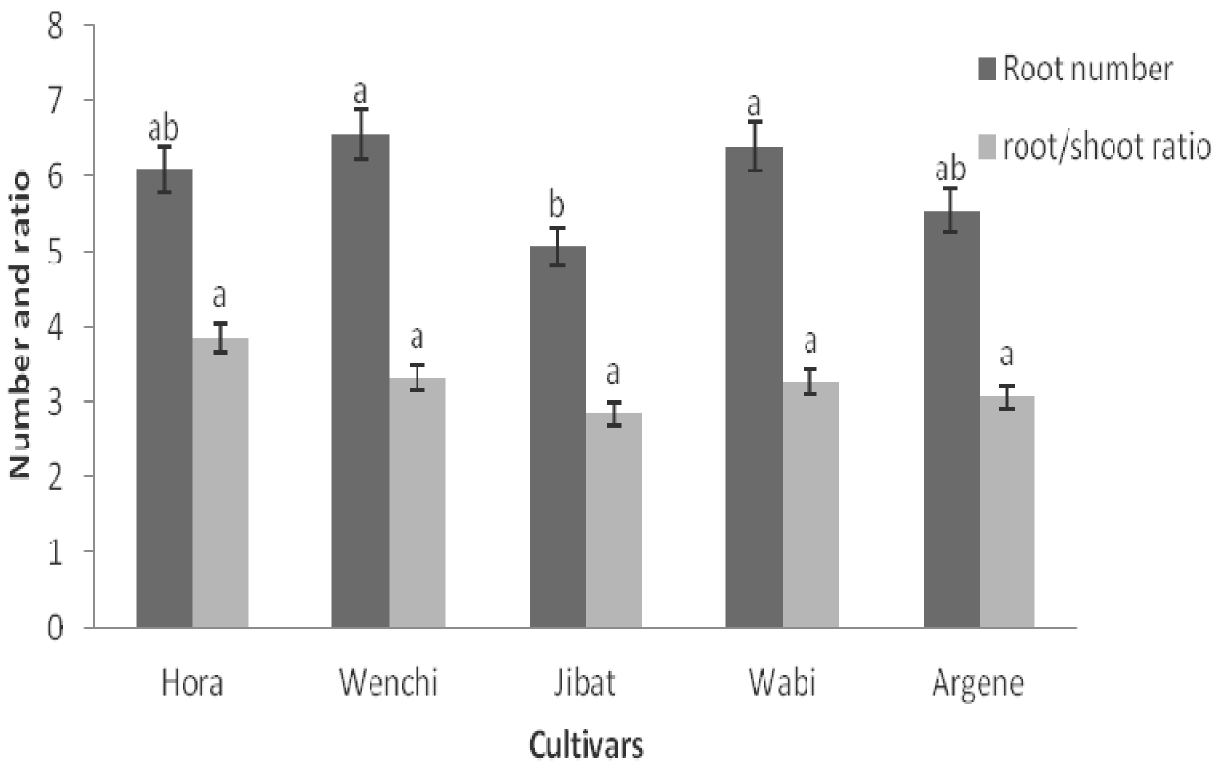

Figure 1. Moisture stress effect on root number and root-to-shoot ratio of maize cultivars.

and dry weights of shoot under stress could be attributed to the accumulation of organic and inorganic solutes and due to the higher growth because of osmotic adjustment. Almaghrabi (2012) reported that PEG caused a greater reduction in fresh and dry weights of shoot and root at higher concentrations compared with control.

Root number, root-to-shoot ratio, and tolerance index

Maize cultivars differed significantly in root number, but not in root-to- shoot ratio. Maximum root number was observed on cultivars Wenchi and Wabi, while the lowest was recorded on Jibat (Figure 1). Wenchi and Hora cultivars exhibited maximum and minimum tolerance indices, respectively to moisture stresses (Figure 2). High number of roots increases the ability of the crop to extract moisture from the growing rhizosphere under moisture stress condition.

Significant difference was observed in root number with increase in the levels of moisture stress (Figure 3). Treatments 120 and 180 g/L PEG gave the maximum root number, while the least was observed with 300 g/L PEG level. Treatment 240 g/L PEG recorded maximum

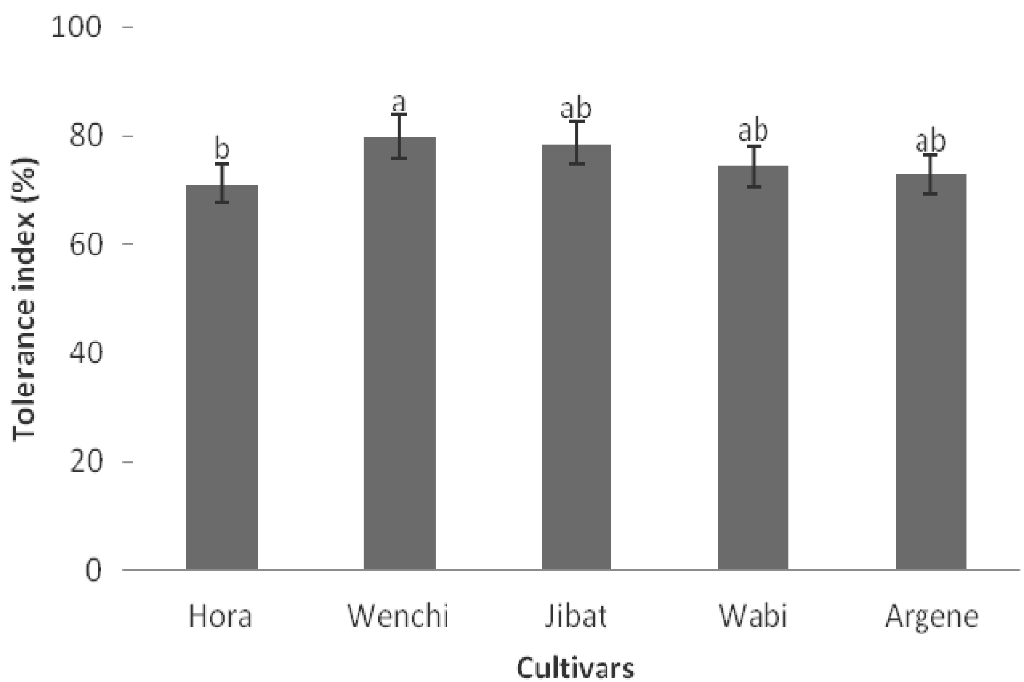

Figure 2. Effect of moisure stress on tolerance index of maize cultivars.

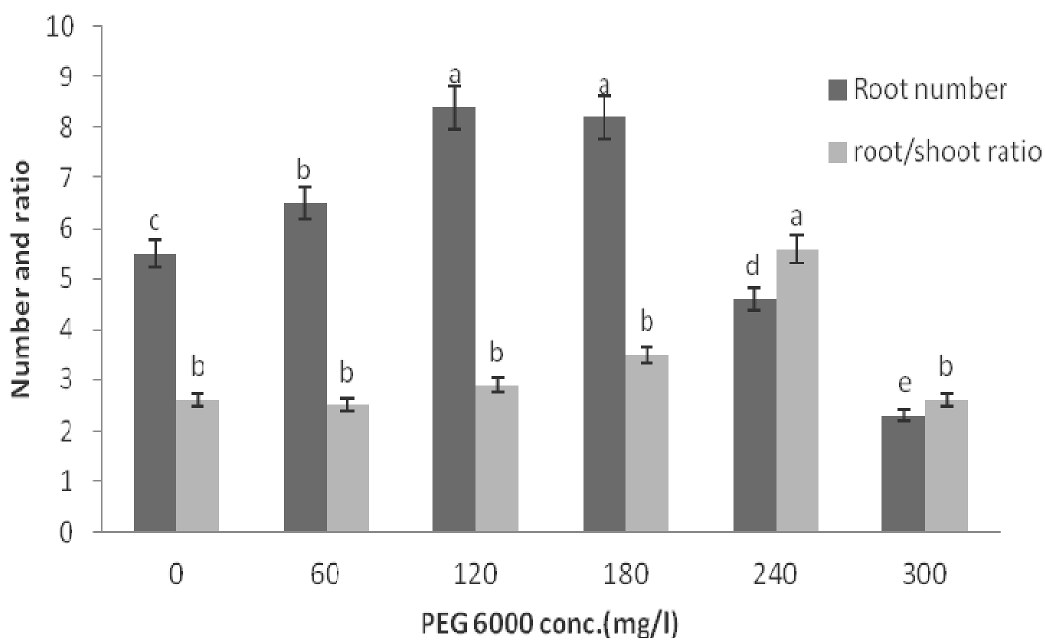

Figure 3. Moisture stress effect on root number and root-to-shoot ratio of maize.

root-to-shoot ratio, which could be due to the minimal shoot growth compared to the root growths. Tolerance index decreased with increase in PEG concentrations beyond 60 g/L (Figure 4). Maximum tolerance index was observed in 60 g/L and the least was observed in 300 g/L treatments. Similar results were reported in wheat by Almaghrabi (2012).

Conclusion

Highland maize cultivars showed differential response to

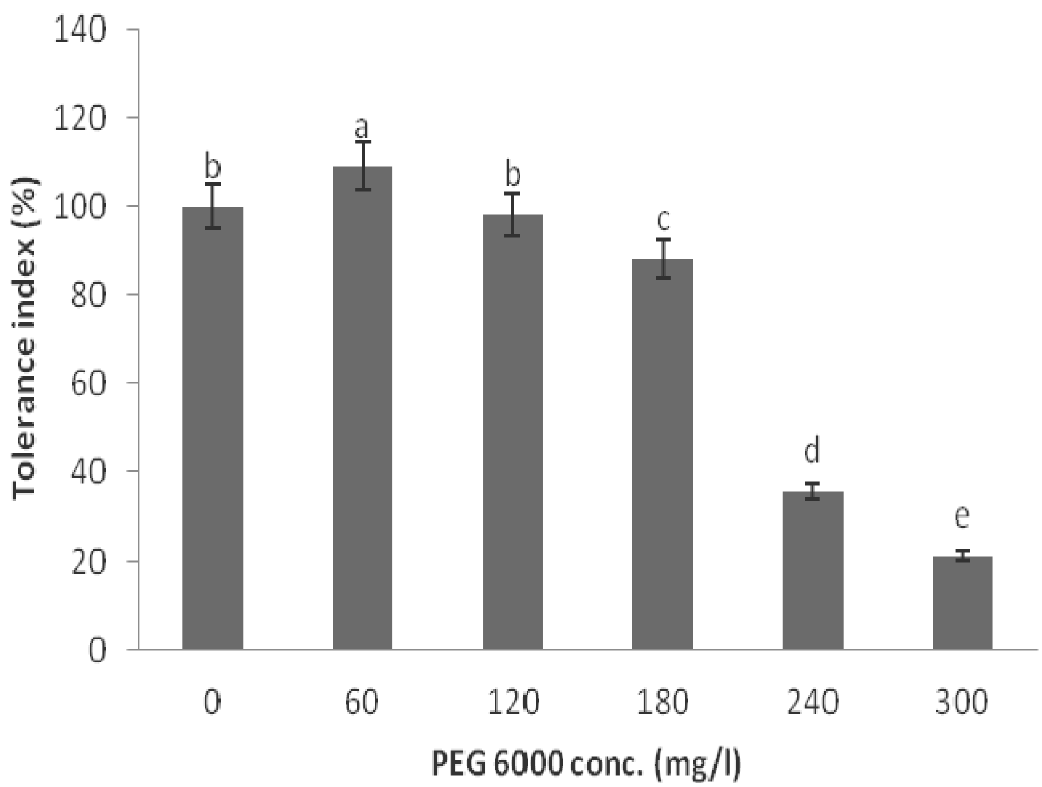

Figure 4. Effect of moisure stress on tolerance index of maize.

water stress at germination and early seedling growth stages. Cultivars varied for germination percentage and rate, shoot and root lengths, root number, and shoot and root fresh weight. Cultivar Wenchi was found relatively tolerant to moisture stress induced by PEG. Increase in PEG 6000 concentrations decreased germination percentage and rate, while shoot and root lengths, and shoot fresh and dry weights decreased beyond 60 g/L. Root fresh and dry weights increased up to 120 g/L PEG, but further increase in stress negatively influenced cultivars tolerance.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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