

GERMINATION AND SEEDLING CHARACTERISTICS OF SILAGE MAIZE CULTIVARS UNDER DIFFERENT DROUGHT LEVELS

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Abstract

This study aims to determine the germination and seedling growth responses of silage maize (*Zea mays* L.) under different levels of drought stress, in order to identify sensitive and tolerant cultivars. Nine different silage maize cultivars (Samada 07, Hido, Bodega, DKC 7240, AGA, Hacıbey, Pioneer 2105, M16S45 and PR32W86) were used. Drought stress conditions (0, 5, 10, 15 and 20%) were provided using polyethylene glycol (PEG-6000) material. Statistically significant ($p < 0.01$) differences were found between varieties and drought levels in terms of all germination and seedling development parameters. As a result, the negative effects of drought stress were observed at 10-15% drought levels in germination traits and at 5% drought level in seedling growth parameters. Among the silage maize cultivars, AGA stood out for its higher tolerance in terms of germination traits, while M16S45 was more tolerant in terms of seedling growth parameters compared to the other cultivars.

Introduction

In sustainable agriculture, abiotic stress factors are among the most important factors limiting production. Stress-induced damages and losses on plants may vary depending on the plant species and its ability to tolerate and adapt to stress. The effect of drought stress depends on the intensity, duration, the growth stage of the plant at the time of stress, and the genotype of the plant (Pawar and Veena 2020). Plants are known to be most sensitive to drought stress, especially during the germination and seedling stages, and it directly affects the subsequent growth and yield periods of the plant (Yousefi *et al.* 2020). Measures that can be taken against drought stress include water-saving irrigation methods, determining the number of plants per unit area, soil ridging and mulching, and these measures play an effective role in reducing or completely eliminating the negative effects of drought (Wu *et al.* 2020).

The maize (*Zea mays* L.) plant, which holds an important place in agricultural production, serves as a significant raw material source for the food industry. Among environmental stress factors, drought stress is one of the major constraints, particularly in maize, leading to yield losses (Hassan *et al.* 2016). Depending on the intensity, duration, and growth stage of the plant, maize yield loss ranges from 30 to 90% (Kathirvelan *et al.* 2025). Specifically, the vegetative stage, flowering, and grain filling stages are the most sensitive periods to drought stress, with yield losses of up to 25, 50 and 21%, respectively, occurring during these stages (Sah *et al.* 2020). Considering the environmental factors associated with global climate change, the development and/or use of resistant cultivars with appropriate genetic characteristics is of great importance in reducing stress against drought stress (Açıkbaş 2025). This study aims to determine the germination and seedling growth responses of silage maize cultivars under different levels of drought stress, to screen out sensitive and tolerant cultivars.

Materials and Methods

The research was conducted in the Department of Field Crops, Faculty of Agriculture, Siirt University. Nine silage maize (*Z. mays*) plant materials namely; Samada 07, Hido, Bodega, DKC

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7240, AGA, Hacibey, Pioneer 2105, M16S45 and PR32W86 cultivars were used. Five different drought stress levels (0, 5, 10, 15, and 20%) were used using polyethylene glycol (PEG-6000) material. The laboratory experiment was designed according to a split-plot design in randomized complete with four replications. The drought stress levels were determined by based on weight/volume.

In each Petri dish (90 x 15 mm), 25 seeds of uniform size were placed between two layers of filter paper for sowing. Initially, 5 ml of solution (PEG-6000 solution) was applied to each Petri dish, and in the following days, appropriate drought solutions were added according to the dryness condition of the Petri dishes. The Petri dishes were left to germinate in a dark environment at a temperature of $25 \pm 1^\circ\text{C}$. The number of germinated seeds was recorded daily for 10 days. Germination was determined based on the criteria reported by Scott *et al.* (1984) and where plants with a rootlet of at least 2 mm were considered as germinated.

Measurements were made on 10 randomly selected plants from each Petri dish, and in Petri dishes where there was insufficient germination due to drought stress, measurements were made only on the germinated plants. The study examined germination characteristics, including germination percentage (GP), mean germination time (MGT), germination uniformity coefficient (CUG), germination energy (GE), and germination index (GI), as well as seedling characteristics such as seedling fresh and dry weight (SFW and SDW, respectively), seedling vigor index (SVI) and water content (WC). The formulas and references for the germination and seedling growth parameters examined in the study are provided in Table 1. The SFW were determined by weighing the seedlings, which were cleaned of surface water and weighed on a precision balance. The samples with measured SFW were subjected to a drying process in an oven at 80°C for 48 hrs to obtain their SDW.

Table 1. Formulas and references related to some of the parameters examined.

Parameter	Equation	Equality explanation	References
GP	$GP = (NGS/TS) \times 100$	NGS is the number of normally germinated seeds, TS is the total number of seeds used.	Scott <i>et al.</i> (1984)
MGT	$MGT = \Sigma(N_i T_i / N_i)$	N_i is the number of seeds germinated on day T_i , T_i is the number of days counted from the beginning of germination.	Ellis and Roberts (1981)
CUG	$CUG = \Sigma n / \Sigma [(MGT - t)^2 n]$	t is the time in days, starting from day 0, the day of sowing, n is the number of seeds completing germination on day t .	Bewley and Black (1994)
GE	$GE = (T_1/N) \times 100$	T_1 is the number of seeds germinated on the first day, N is the total number of seeds.	Li <i>et al.</i> (2020)
GI	$GI = \Sigma(G_i/T_i)$	G_i is the GP at the i^{th} day, and T_i is the days of the germination test duration.	Wang <i>et al.</i> (2004)
SVI	$SVI = GP \times SFW$	GP: Germination percentage SFW: Seedling fresh weight	Kalsa and Abebie (2012)
WC	$WC = (SFW - SDW) / SDW$	SFW: Seedling fresh weight SDW: Seedling dry weight	Wu <i>et al.</i> (2015)

The obtained data were subjected to analysis of variance according to a split-plot design in randomized complete, and the differences between the means were checked by Tukey's multiple comparison test (Açıkgöz and Açıkgöz 2001).

Results and Discussion

Data on germination parameters of silage maize cultivars at different drought levels are given in Table 2. The effects of drought levels and cultivars on all germination parameters were found to be statistically very significant. In addition, variety x drought interaction is statistically significant at $p < 0.01$ level for all germination parameters. Increasing drought levels reduced the GP, with significant decreases at 10%. The highest GP, as an average of the cultivars, was determined to be 93.5, 95.4, and 91.9% at the control, 5 and 10% drought levels, respectively. The lowest value was 65.0% at 20% drought level. When the average GP of silage maize cultivars were examined, the highest GP was found to be 95.3% in the AGA cultivar. The difference in GP between AGA and the Hido (87.5%), M16S45 (93.3%), and Bodega (94.3%) cultivars was found to be statistically insignificant. The lowest GP, with an average drought level of 62.0%, was observed in the Pioneer 2105 cultivar (Table 2).

Table 2. Germination parameter values of maize cultivars under different drought levels.

Cultivars	Drought levels (%)					Average
	0	5	10	15	20	
Germination percentage (GP) (%)						
Samada 07	100.0 a	90.0 abc	100.0 a	86.7 a-d	56.7 e	86.5 BC
Hido	100.0 a	100.0 a	95.0 ab	70.0 cde	73.3 b-e	87.5 ABC
Bodega	96.7 ab	100.0 a	96.7 ab	90.0 abc	88.3 abc	94.3 AB
DKC 7240	78.3 a-e	96.7 ab	73.3 b-e	56.7 e	30.0 f	67.0 D
AGA	100.0 a	100.0 a	100.0 a	90.0 abc	86.7 a-d	95.3 A
Hacıbey	90.0 abc	90.0 abc	80.0 a-e	76.7 a-e	76.7 a-e	82.5 C
Pioneer 2105	80.0 a-e	81.7 a-d	90.0 abc	28.3 f	30.0 f	62.0 D
M16S45	100.0 a	100.0 a	100.0 a	85.0 a-d	81.7 a-d	93.3 AB
PR32W86	96.7 ab	100.0 a	91.7 abc	81.7 a-d	63.3 de	86.5 BC
Average	93.5 A	95.4 A	91.9 A	74.1 B	65.0 C	
Mean germination time (MGT) (day)						
Samada 07	2.5 h-p	2.2 k-q	2.5 h-p	2.7 d-m	3.4 abc	2.7 BC
Hido	2.2 m-q	2.6 f-o	2.7 d-n	3.2 a-g	3.3 a-e	2.8 AB
Bodega	2.1 n-q	2.2 m-q	2.3 j-q	2.4 j-q	2.9 b-k	2.4 D
DKC 7240	2.3 k-q	2.7 d-m	3.0 b-j	3.3 a-e	3.3 a-d	2.9 A
AGA	1.7 q	1.9 pq	2.0 n-q	2.2 m-q	2.4 j-q	2.0 E
Hacıbey	2.0 opq	2.2 l-q	2.7 e-n	2.6 g-o	3.0 a-1	2.5 CD
Pioneer 2105	2.4 i-p	2.8 d-m	3.4 abc	3.1 a-h	3.0 b-j	3.0 A
M16S45	2.0 opq	2.2 m-q	2.6 g-o	2.8 c-l	3.5 ab	2.6 BC
PR32W86	2.4 j-q	2.3 k-q	2.6 g-o	3.2 a-f	3.6 a	2.8 AB
Average	2.2 E	2.3 D	2.6 C	2.8 B	3.1 A	
Germination index (GI)						
Samada 07	8.6 c-g	8.3 c-g	8.4 c-g	6.8 e-k	3.5 lm	7.1 CD
Hido	9.5 bcd	8.1 c-g	7.4 d-j	4.8 kl	4.7 kl	6.9 CD
Bodega	9.5 bcd	9.4 bcd	8.7 c-f	8.0 c-g	6.5 f-k	8.4 B
DKC 7240	7.1 d-k	7.8 c-1	5.3 i-l	3.5 lm	2.0 m	5.1 E
AGA	12.7 a	11.5 ab	9.9 bc	8.6 c-g	7.8 c-h	10.1 A
Hacıbey	9.9 bc	8.3 c-g	6.2 g-k	6.2 g-k	5.4 h-l	7.2 CD
Pioneer 2105	6.8 e-k	6.3 f-k	5.6 h-l	2.1 m	2.0 m	4.6 E
M16S45	10.0 bc	9.5 bcd	8.1 c-g	6.3 f-k	4.8 kl	7.8 BC
PR32W86	8.6 c-g	9.1 b-e	7.6 c-1	5.1 jkl	3.6 lm	6.7 D
Average	9.2 A	8.7 A	7.5 B	5.7 C	4.5 D	
Germination energy (GE)						
Samada 07	63.3 a-1	70.0 a-g	53.3 c-k	35.0 g-o	6.7 no	45.7 CD
Hido	86.7 abc	43.3 f-n	35.0 g-o	16.7 k-o	10.0 m-o	38.3 DE
Bodega	91.7 ab	83.3 a-d	66.7 a-h	63.3 a-1	23.3 j-o	65.7 B

Table 2 contd.

DKC 7240	58.3 b-j	51.7 c-k	23.3 j-o	1.0 o	3.3 o	27.5 EF
AGA	73.3 a-f	76.7 a-f	96.7 a	81.7 a-e	65.0 a-h	78.7 A
Hacıbey	65.0 a-h	70.0 a-g	26.7 i-o	33.3 g-o	20.0 k-o	43.0 CD
Pioneer 2105	45.0 e-m	31.7 h-o	13.3 i-o	6.7 no	6.7 no	20.7 F
M16S45	100.0 a	83.3 a-d	43.3 f-n	26.7 i-o	3.3 o	51.3 C
PR32W86	66.7 a-h	73.3 a-f	48.3 d-l	1.0 o	0.8 o	38.0 DE
Average	72.2 A	64.8 A	45.2 B	29.3 C	15.4 D	
Coefficient of uniformity of germination (CUG)						
Samada 07	40.3 c-1	40.5 c-1	40.2 c-1	31.8 h-m	16.6 no	33.9 CD
Hido	46.3 a-f	38.6 c-1	35.7 e-k	22.4 mn	22.3 mn	33.1 D
Bodega	47.1 a-e	46.2 b-f	42.0 b-h	38.5 d-1	31.0 h-m	41.0 B
DKC 7240	34.1 g-1	35.6 f-k	24.9 k-n	17.2 no	9.5 o	24.2 E
AGA	57.7 a	52.6 ab	49.2 a-d	41.9 b-h	37.0 e-j	47.7 A
Hacıbey	45.6 b-f	40.7 c-1	30.0 i-m	29.9 i-m	25.3 k-n	34.3 CD
Pioneer 2105	32.8 g-m	30.1 i-m	26.2 j-n	9.8 o	9.7 o	21.7 E
M16S45	50.0 abc	46.2 b-f	39.1 c-1	30.0 i-m	23.4 lmn	37.7 BC
PR32W86	40.8 c-1	45.5 b-g	35.8 e-k	25.2 k-n	17.5 no	32.6 D
Average	43.8 A	41.6 A	35.9 B	27.4 C	21.4 D	
Tukey value/ Significance level						
	Drought (D)	Cultivar (C)		D x C		
GP	5.56**	8.55**		24.52**		
MGT	0.14**	0.22**		0.65**		
GI	0.55**	0.83**		2.44**		
GE	8.37**	12.85**		36.88**		
CUG	2.61**	4.01**		11.46**		

Differences between means indicated by the same letter in the same column/row/group are not statistically significant.

** : Significant at $p < 0.01$ level.

In the study, increasing drought levels delayed the MGT of the cultivars. While germination occurred in an average of 2.2 days in the control (0%) group, this value increased to 3.1 days at the 20% drought level. Based on the average drought levels, when the effect of cultivars on MGT was examined, the earliest germination was observed in the AGA cultivar at 2 days. The latest germination times were recorded in the DKC 7240 cultivar at 2.9 days and the Pioneer 2105 cultivar at 3 days (Table 2).

The GI, GE, and CUG were significantly reduced with the increase in drought levels. These reductions became statistically significant particularly from the 10% drought level to onward. The highest values for the mentioned germination parameters were observed in the control group (9.2, 72.2, and 43.8, respectively) and at the 5% drought level (8.7, 64.8, and 41.6, respectively). The lowest values were recorded at the 20% drought level. When the differences among cultivars in terms of GI, GE, and CUG were examined, the highest values for all three parameters were recorded in the AGA cultivar, with 10.1, 78.7, and 47.7, respectively. The lowest values for GI and CUG were observed in the DKC 7240 and Pioneer 2105 cultivars, while for GE, the lowest value was recorded only in the Pioneer 2105 cultivar (Table 2).

Negatively affected the germination process of maize cultivars due to increasing drought levels. Majid *et al.* (2020) reported that increasing levels of drought (PEG) reduced the germination characteristics of plants due to higher concentration of osmolytes (proline, glycine betaine and soluble sugars), reactive oxygen species (hydrogen peroxide and superoxide anion) and lipid peroxides in plants. In studies conducted with different plant species, it has been reported that drought stress negatively affects germination characteristics depending on the severity and duration (Borawska-Jarmulowicz *et al.* 2017, Pantola *et al.* 2017, Çiğ *et al.* 2021). In addition, Khodrahmpour (2011) reported in his study that germination time was prolonged as the drought level increased in maize plants. These results in the literature support the present study.

In the study, it was observed that silage maize cultivars had different responses to drought in terms of germination characteristics. Depending on the genotypic differences in terms of germination parameters, maize cultivars were affected at different drought levels. These differences between varieties in terms of germination characteristics have also been reported in studies conducted with some other plant species (Pham *et al.* 2023, Açıkbaş, 2025, Erdoğan and Orhan 2025).

The data on seedling growth characteristics of maize cultivars under different drought levels are presented in Table 3. The effects of drought levels and cultivars on all seedling growth parameters were found to be highly significant ($p < 0.01$). In addition, the cultivar x drought interaction for the seedling parameters was also found to be statistically significant at the $p < 0.01$ level (Table 3).

When the average results of silage maize cultivars were examined in terms of seedling growth parameters such as SFW, SDW and SVI, the highest values were recorded in the control group, with 1140.4, 60.5 and 107.3 mg, respectively. The lowest values for SFW and SVI were determined at 20%, with 489.6 and 32.6 mg, respectively. For SDW, the lowest values were obtained at 15 (36.3 mg) and 20% (33.3 mg) drought levels. When the differences among cultivars were examined in terms of SFW and SDW, the highest values were obtained in the M16S45 cultivar, with 977.9 and 66.4 mg, respectively and lowest in DKC 7240 (645.2 mg), while the lowest SDW was recorded in the Bodega cultivar (29.6 mg). In terms of SVI, M16S45 stood out with a value of 93.1, whereas DKC 7240 had the lowest SVI with a value of 47.6 (Table 3).

In terms of WC, the highest values in silage maize cultivars were observed at the 0 (19.0) and 5% (19.7) drought levels, while the lowest at 20% (14.5). Among the cultivars, the highest WC was found in Bodega (21.8) and PR32W86 (21.2), while the lowest in Hido cultivar (12.4) (Table 3).

The germination and seedling development stages are vital for the healthy growth of a plant. However, drought during the germination process significantly hinders the formation of healthy seedlings. In the study, silage maize cultivars showed different responses in all examined seedling parameters, and varying effects were observed under different drought levels. Indeed, many studies have also reported that seedling development parameters exhibit different responses depending on genotypic factors (Yılmaz and Kısakürek 2020, Çiğ *et al.* 2021, Çifçi and Açıkbaş 2023). Many studies conducted on different plant species and cultivars have reported that when seedlings are exposed to drought stress, they are adversely affected in terms of seedling fresh and dry weights, seedling vigor index, and water content (Khan *et al.* 2019, Yalçın *et al.* 2021, Bilir Ekbic *et al.* 2022, Açıkbaş 2025, Iiang Cai *et al.* 2025).

As a result, the negative effects of drought stress were observed on germination traits at 10-15% drought levels, and on seedling development parameters at the 5% drought level. In other words, it has been understood that silage corn varieties are more sensitive to drought during the seedling development phase than during the germination stage. According to the study results, the drought tolerance exhibited by the cultivars varied. Among the silage maize cultivars, the AGA cultivar was more tolerant to drought in terms of germination traits, while the M16S45 cultivar showed better tolerance in terms of seedling development parameters and stood out. According to these results, varieties with high drought tolerance should be selected for silage maize cultivation in drought-affected regions. In addition, these results will guide the determination of traits that provide advantages in drought conditions, the understanding of tolerance mechanisms and the provision of data for breeding programs. Considering climate change and increasing drought risks, identifying drought-tolerant maize varieties supported also by field trials in the future is of critical importance for sustainable production.

Table 3. Seedling growth parameter values of maize cultivars under different drought levels.

Cultivars	Drought levels (%)					Average
	0	5	10	15	20	
Seedling fresh weight (SFW) (mg)						
Samada 07	1256.7 b	985.7 e-1	902.0 g-k	792.6 j-n	433.3 s	874.1 B
Hido	1235.2 bc	916.0 f-j	447.8 rs	441.0 s	407.5 s	689.5 EF
Bodega	909.0 f-k	926.9 f-j	522.0 qrs	615.2 o-r	435.7 s	681.8 EF
DKC 7240	1051.9 d-g	862.6 h-m	514.8 qrs	424.2 s	372.7 s	645.2 F
AGA	1117.3 b-e	896.9 g-k	869.9 h-l	696.9 m-p	626.4 n-q	841.5 B
Hacıbey	1172.7 bcd	859.4 h-m	738.2 k-o	695.1 m-p	408.9 s	774.9 C
Pioneer 2105	979.7 e-1	1008.5 d-h	769.8 j-o	526.2 p-s	508.8 qrs	758.6 CD
M16S45	1564.1 a	1076.9 c-f	832.7 i-m	722.2 l-o	693.7 m-p	977.9 A
PR32W86	977.5 e-1	882.5 g-l	644.7 n-q	504.5 qrs	519.1 qrs	705.7 DE
Average	1140.4 A	935.1 B	693.5 C	602.0 D	489.6 E	
Seedling dry weight (SDW) (mg)						
Samada 07	79.2 ab	71.0 bc	54.9 e-1	48.7 g-k	27.3 o-r	56.2 B
Hido	78.8 ab	70.0 bcd	51.7 f-j	32.6 l-r	25.8 pqr	51.8 BC
Bodega	37.3 j-r	28.9 n-r	28.6 n-r	26.9 o-r	26.2 o-r	29.6 G
DKC 7240	44.3 g-m	37.0 k-r	33.0 l-r	24.1 r	40.9 i-o	35.8 EF
AGA	65.7 b-f	45.8 g-l	40.5 i-p	38.5 j-r	39.1 j-q	45.9 D
Hacıbey	68.3 b-e	57.2 c-g	54.0 e-1	33.5 l-r	25.0 qr	47.6 CD
Pioneer 2105	44.0 g-m	33.9 l-r	30.9 m-r	42.5 h-n	46.2 g-l	39.5 E
M16S45	89.5 a	79.4 ab	71.0 bc	56.2 d-h	36.1 k-r	66.4 A
PR32W86	37.1 j-r	34.5 k-r	29.6 m-r	23.8 r	33.1 l-r	31.6 FG
Average	60.5 A	50.9 B	43.8 C	36.3 D	33.3 D	
Seedling vigor index (SVI)						
Samada 07	125.7 b	88.7 d-g	90.2 def	68.7 g-l	24.6 stu	79.6 B
Hido	123.5 b	91.6 cde	42.5 m-s	31.4 r-u	29.9 r-u	63.8 C
Bodega	87.9 d-g	92.7 cde	50.7 l-r	55.3 l-p	38.4 o-s	65.0 C
DKC 7240	82.7 e-h	83.4 e-h	37.2 p-s	23.8 stu	11.2 u	47.6 D
AGA	111.7 bc	89.7 d-g	87.0 d-g	62.7 h-m	54.3 l-p	81.1 B
Hacıbey	105.5 bcd	77.1 e-k	58.7 j-o	53.8 l-q	31.4 r-u	65.3 C
Pioneer 2105	78.2 e-j	82.3 e-1	69.3 f-l	15.8 tu	14.4 tu	52.0 D
M16S45	156.4 a	107.7 bcd	83.3 e-h	61.4 i-n	56.6 k-p	93.1 A
PR32W86	94.3 cde	88.3 d-g	59.2 j-o	41.2 n-s	32.9 q-t	63.2 C
Average	107.3 A	89.1 B	64.2 C	46.0 D	32.6 E	
Water content (WC)						
Samada 07	14.9 g-p	12.9 j-p	15.6 f-p	15.3 f-p	14.9 g-p	14.7 CDE
Hido	14.7 h-p	12.1 l-p	7.7 p	12.7 k-p	14.8 g-p	12.4 E
Bodega	23.4 a-f	31.2 a	17.3 c-n	21.9 b-1	15.6 f-p	21.8 A
DKC 7240	22.9 b-g	22.4 b-h	14.7 h-p	16.7 d-o	8.8 op	17.1 BCD
AGA	16.0 f-o	18.9 c-m	20.6 c-k	17.1 d-n	15.0 g-p	17.5 BC
Hacıbey	16.2 e-o	14.0 i-p	12.7 k-p	20.2 c-l	15.4 f-p	15.7 CD
Pioneer 2105	21.3 b-1	28.8 ab	24.4 a-e	11.5 m-p	10.5 nop	19.3 AB
M16S45	16.5 d-o	12.6 k-p	10.8 m-p	11.9 m-p	20.6 c-k	14.5 DE
PR32W86	25.4 abc	24.6 a-d	21.0 b-j	20.4 c-k	14.7 g-p	21.2 A
Average	19.0 A	19.7 A	16.1 BC	16.4 B	14.5 C	
Tukey value/ Significance level						
	Drought (D)	Cultivar (C)			D x C	
SFW	38.95**	59.53**			170.83**	
SDW	3.35**	5.12**			14.68**	
SVI	4.78**	7.35**			21.09**	
WC	1.85**	2.85**			8.16**	

*: Differences between means indicated by the same letter in the same column/row/group are not statistically significant.

** : Significant at $p < 0.01$ level.

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