



## Effects of hydrogel polymer on grain yield, some physiological characteristics, and antioxidant enzyme activity of maize in response to drought stress

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### Article Info

#### Article type:

Research article

#### Article history:

Received: December 12, 2025

Revised: February 21, 2026

Accepted: March 7, 2026

Published online: May 22, 2026

#### Keywords:

Ion content,  
Maize,  
Photosynthetic pigments,  
Superabsorbent polymer,  
Water deficit.

### Abstract

**Objective:** Drought stress has destructive effects on the growth and performance of crops. The application of superabsorbent polymer can provide water and some nutrients to crops during the growth period. This experiment aimed to evaluate the effect of hydrogel polymer and drought stress on the characteristics of maize (variety MV 524 Maxima).

**Methods:** The experiment was conducted as a split-plot design based on a randomized complete block design with three replications. The drought stress levels, 60 mm (control), 120 mm, and 180 mm, based on evaporation from the evaporation pan, were assigned to the main plots. The levels of hydrogel polymer, 0 (control), 75, 150, and 225 kg/ha were arranged in subplots. Hydrogels were mixed and applied at a depth of 20-30 cm in the soil. Samples were taken from young leaves at the seed-filling stage to measure photosynthetic pigments and antioxidant enzymes activity. Also, at maturity, mineral elements (nitrogen, phosphorus, and potassium) in the grains, biomass, grain yield, and yield components, including 1000-kernel weight, number of kernels per row, number of kernel rows per ear, and plant height were measured.

**Results:** Drought stress reduced photosynthetic pigments (chlorophyll "a", chlorophyll "b" and carotenoids), N, P, and K content in the grains, the number of kernels per row, number of kernel rows per ear, and 1000-kernel weight. Also, drought stress increased the activities of catalase (CAT) and glutathione peroxidase (GPX). The application of hydrogel polymer had a positive effect on maize plants and at all drought levels, the highest grain yield, biomass, and number of kernels per row were obtained with the highest amount of hydrogel polymer (225 kg/ha). However, hydrogel polymer decreased CAT activity and anthocyanin content, but it did not change the number of kernel rows, 1000-kernel weight, ion content in the grains, GPX activity, chlorophyll "a" and "b", and carotenoids in the maize leaves.

**Conclusion:** The results indicated that the application of 225 kg/ha hydrogel polymer had a beneficial effect on maize and mitigated the harmful effects of drought stress.

**Cite this article:** Shouridehdel M, Heidari M, Abbasdokht H. 2026. Effects of hydrogel polymer on grain yield, some physiological characteristics, and antioxidant enzyme activity of maize in response to drought stress. *J Plant Physiol Breed.* 16(2): 39-52. <https://doi.org/10.22034/jppb.2026.70686.1401>



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Publisher: University of Tabriz

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## Introduction

Drought stress adversely affects crop production worldwide. It influences the metabolism and physiological processes in crops (Heidari and Karami 2014). The impact of lack of sufficient water on plants is classified as invisible and visible symptoms. A decrease in plant height, number and area of leaves, leaf wilting, and delay in the occurrence of buds and flowers, are the visible syndromes (Valliyodan and Nguyen 2006). Disorders in the water status of different plant organs and a decrease in chlorophyll content and damage to cytoplasmic membranes are regarded as invisible syndromes (Grzesiak 2001). Drought stress reduces the turgor and water potential of plant cells, increasing the solute content in the cytosol. Then, cell enlargement and production decrease (Reddy *et al.* 2004).

Maize (*Zea mays* L.) as a cereal crop is sensitive to drought stress, especially at the silking and pollination stages (Otegui *et al.* 1995). Lack of sufficient water in the soil weakens metabolic activity, decreases chlorophyll content and photosynthesis, leading to biomass and yield reduction in maize (Bu *et al.* 2010). According to Ghassemi *et al.* (2020), drought stress considerably reduced 100-kernel weight, ear length, number of kernels per row, number of kernel rows per ear, number of kernels per ear, dry weight of husks, and grain yield in maize. Ghassemi Golezani and Mousavi (2022) reported that drought stress reduced leaf water content, leaf area index, chlorophyll content, and grain yield in maize.

Several organic and chemical materials, as moisture retainers, can be used in the soil to improve crop production under low-irrigation or drought-stress conditions. Super-absorbent polymers (hydrogels) offer a promising solution for improving crop production by making better use of existing soil moisture. When integrated into the soil, they act as reservoirs that capture water and nutrients, releasing them incrementally to satisfy plant demands (Dehkordi *et al.* 2013; Gunes *et al.* 2016). Research demonstrates that plants grown in hydrogel-amended soils develop significantly greater root biomass than those in untreated soils. This enhanced root architecture enables more efficient

uptake of water and nutrients, proving particularly advantageous during periods of water deficit (Nnadi and Brave 2011). Poormeidany and Khakdaman (2006) stated that the application of hydrogel reduced the irrigation interval and the amount of water consumed with acceptable seedling survival. In wheat, hydrogel application promotes root development, enhancing drought tolerance and ultimately improving yield (Ali *et al.* 2024). When hydrogels are added to the soil, they absorb a large amount of water and nutrients and release them to the plant slowly. Then, plant growth can be improved with limited water supply (Yazdani *et al.* 2007; Islam *et al.* 2011).

This study aimed to evaluate the effect of hydrogel polymer on agronomic traits and some physiological and biochemical characteristics of maize under water-deficit stress conditions.

## Materials and Methods

This study was conducted at the Agricultural College, Shahrood University of Technology, Iran (36° 29' N and 55° 57' E; 1366 m a.s.l) in 2022. The soil in the field was clay loam in texture, with a pH of 7.71, EC of 1.65 ds.m<sup>-1</sup>; organic carbon of 0.29%, N of 0.04%, and 221 and 10 ppm of available K and P, respectively. Field capacity, wilting point and available water holding capacity were 298, 188, and 93 mm, respectively.

The experiment was conducted as a split-plot design based on a randomized complete block design with three replications. The drought stress levels [60 mm (control), 120 mm, and 180 mm evaporation from the surface of the evaporation pan] were included in the main plots. The levels of hydrogel polymer, 0 (control), 75, 150, and 225 kg/ha were arranged in subplots. Hydrogel was applied and mixed at a depth of 20-30 cm in the soil. The maize variety MV 524 Maxima, was sown on 22 May, 2022. The hydrogel polymer used in this study was Super AB A200.

In each plot, there were six rows with 0.45 m width and 4 m length. Before sowing the seeds, 200, 150, and 100 kg/ha of N (urea), P (super phosphate) and K (potassium sulfate), respectively, were added to the soil. Half of the N was used immediately before planting and the other half at the 6-8 leaf stage. Seeds were placed at a depth of 3-5 cm. Drought stress started from the 5-6 leaf stage by adjusting the irrigation interval based on the stress level until the end of the growth period. To measure antioxidant enzyme activities, photosynthetic pigments, and some physiological traits, samples were taken from young leaves at the seed-filling stage. The samples were immediately powdered with liquid nitrogen after collection, stored in a freezer at -80 °C, and then the physiological and biochemical characteristics were measured.

### ***Antioxidant enzyme activity***

A 0.2 g sample of fresh leaf tissue, homogenized in liquid nitrogen, was transferred into 15 mL tubes and 2.5 mL of extract buffer (0.1M Tris, pH 7.8, and 30% glycerol) was added to the tubes. Then, the samples were centrifuged at 15,000g for 15 min at 4 °C, and the supernatant saved for enzyme assays. Catalase (CAT) activity was measured by a spectrophotometry, following H<sub>2</sub>O<sub>2</sub> treatment at 240 nm (Bailly *et al.* 1996). Glutathione peroxidase (GPX) activity was measured according to Roxas *et al.* (1997).

### ***Photosynthetic pigments***

Chlorophyll 'a' and 'b' and carotenoids in the leaves, were extracted with 80% acetone and estimated according to Arnon (1967). Chlorophyll 'a' and 'b' and carotenoids were measured at 645, 663, and 440 nm. Also the anthocyanin content in the leaves was measured according to Mita *et al.* (1997).

### ***Mineral elements in the grains***

To determine the K content, the grains were dried at 500 °C, and then, K was measured by a flame photometer (Jenway PFP7, Keison Products, UK). The amount of N in the grains was measured by the Kjeldahl method, and P was determined according to Chapman and Pratt (1961). The vanadate solution was added to the molybdate solution and cooled to room temperature. Then, 250 mL of concentrated HNO<sub>3</sub> was added and diluted to 1 L. Next, 0.5 g of grains was taken into 50 mL volumetric flasks and 10 mL of vanado-molybdate reagent was added to each flask. The volume was adjusted with deionized water. The solution was kept for 30 min. Then, the amount of P was measured with a spectrophotometer at 420 nm. Appropriate standards were run simultaneously.

### ***Yield and yield components***

To measure the grain yield and biomass at maturity, all plants were harvested from the two middle rows in each plot. Then, grain and biomass were determined based on dry weight. Also yield components, including 1000-kernel weight, number of kernels per row, number of kernel rows per ear, and plant height were measured on five plants in each plot.

### ***Statistical analyses***

After analysis of variance, means were compared using the LSD test at  $p \leq 0.05$ . All data were analyzed with SAS software 9.2.

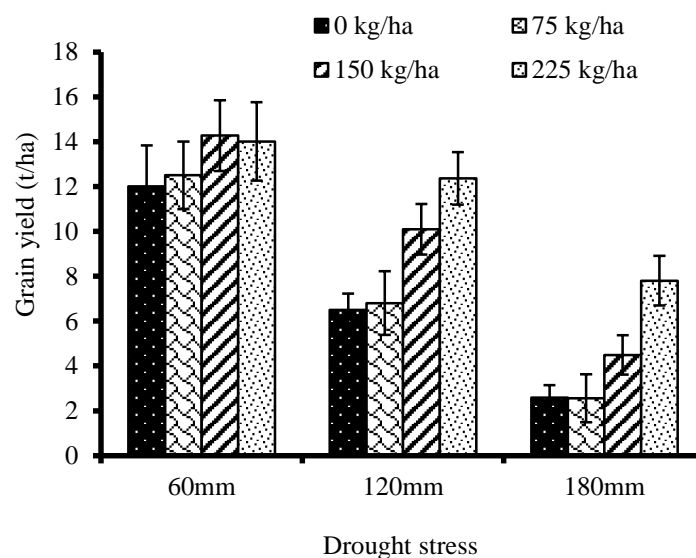
## Results

### *Grain yield, yield components, and plant height*

Analysis of variance in Table 1 showed a significant drought stress  $\times$  hydrogel polymer interaction for grain yield, biomass, and the number of kernels per row in maize plants. As seen in Figures 1, 2, and 3, under normal irrigation conditions (control), the highest grain yield, biomass, and the number of kernels per row were obtained at the higher levels of hydrogel polymer (150 and 225 kg/ha). By increasing the drought level, these traits were reduced, but the application of hydrogel polymer at the rate of 225 kg/ha mitigated the harmful effects of drought stress on these traits.

Among the yield components, drought stress had a significant effect on the number of kernel rows per ear and 1000-kernel weight; however, the application of hydrogel polymer had no significant effect on these traits (Table 1). By increasing the drought level from the control to severe stress (180 mm evaporation from the pan), the number of kernel rows per ear and 1000-kernel weight decreased. This decrease was 21.3% and 19.9%, respectively (Table 2).

Drought stress and the application of hydrogel polymer had a significant effect on plant height, but their interaction was not significant (Table 1). Plant height declined as drought stress increased. Under severe stress conditions, plant height decreased by about 20.6%, compared to the control. However, the application of hydrogel polymer increased plant height and the highest plant height was obtained at 225 kg/ha (Table 2).



**Figure 1.** Effect of drought stress and hydrogel polymer application on maize grain yield; LSD 5% = 1.43.

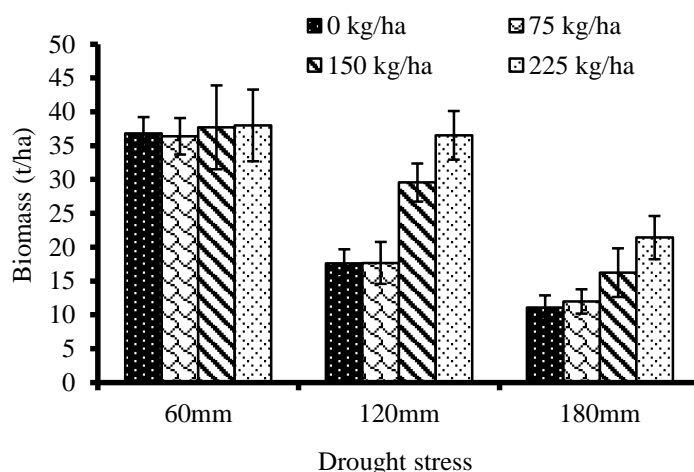
**Table 1.** Effects of drought stress and hydrogel polymer on grain yield, photosynthetic pigments, mineral elements, and antioxidant enzyme activity in maize.

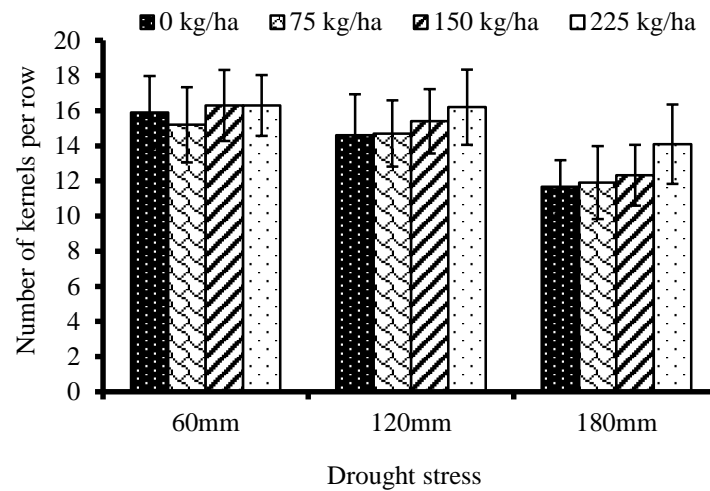
Source of variation	df	Mean squares							
		Grain yield	Biomass	Number of rows per ear	Number of kernels per row	1000-kernel weight	Plant height	Chl a	Chl b
Block	2	5.47	27.15	2.96	13.63	3.94	403.96	0.0003	0.00036
Drought (D)	2	235.4**	1466.7**	39.79*	2093.0**	8285.4*	5017.5**	0.33**	0.0083*
Error a	4	2.76	10.54	3.91	10.35	1065.1	122.2	0.0036	0.0006
Hydrogel (H)	3	37.68**	216.16**	4.56	253.6**	289.1	1078.5*	0.039	0.0013
D × H	6	3.5*	57.09*	0.67	62.42*	91.47	98.6	0.007	0.00024
Error b	18	1.001	11.35	4.11	19.76	721.1	274.3	0.013	0.0006
CV (%)		11.2	12.9	13.9	14.8	11.5	9.3	21.6	10.4

**Table 1** continued

Source of variation	df	Mean squares						
		Carotenoids	Anthocyanin	CAT	GPX	N	P	K
Block	2	0.0025	0.0006	0.000001	1.32	0.062	0.00004	0.0004
Drought stress (D)	2	0.0109*	0.017**	0.00037**	193.3*	0.193*	0.0006*	0.027**
Error a	4	0.0011	0.00016	0.0000009	11.55	0.023	0.00007	0.00023
Hydrogel (H)	3	0.001	0.003*	0.000006*	9.90	0.0194	0.000088	0.0026
D × H	6	0.00021	0.0007	0.000003	3.37	0.0033	0.0000087	0.0006
Error b	18	0.0027	0.00059	0.0000018	11.19	0.0112	0.000073	0.0012
CV (%)		8.1	12.7	7.2	14.2	7.1	4.4	8.8

\*, \*\*: Significant at  $p \leq 0.05$  and  $p \leq 0.01$ , respectively; Chl a: Chlorophyll a, Chl b: Chlorophyll b, CAT: Catalase, GPX: Gayacol peroxidase, N: Grain nitrogen, P: Grain phosphorus, K: Grain potassium.

**Figure 2.** Effect of drought stress and hydrogel polymer application on maize biomass; LSD 5% = 3.51.



**Figure 3.** Effect of drought stress and hydrogel polymer application on the number of kernels per row in maize; LSD 5% = 4.02.

### *Antioxidant enzyme activity*

The CAT activity in the leaf tissues of maize was significantly affected by drought stress and the application of hydrogel polymer, but their interaction was not significant (Table 1). By increasing the drought level from the control to severe stress, CAT activity increased. This increase was 41.6%. The highest CAT activity was obtained at 75 kg/ha of hydrogel polymer and the control treatment. By increasing the application of hydrogel polymer, CAT activity decreased and the lowest CAT activity was obtained at 225 kg/ha (Table 2).

Only drought stress affected GPX significantly, and hydrogel polymer and its interaction with drought stress had no significant effect on GPX activity in maize leaves (Table 1). Similar to CAT, drought stress increased GPX activity, and the highest GPX activity was observed under severe stress conditions (Table 2).

### *Ion content*

Analysis of variance showed that drought stress had a significant effect on the N, P, and K content in maize grains; however, hydrogel polymer and its interaction with drought stress did not have significant effects on these nutrients (Table 1). By increasing the drought level, the amounts of N, P, and K in the grains declined. Under severe drought stress conditions, the decline was equivalent to 15.5%, 10%, and 20.4% for N, P, K, respectively (Table 2).

**Table 2.** Yield components, photosynthetic pigments, ion content, and antioxidant enzyme activity in maize plants as affected by drought stress and the application of hydrogel polymer.

Factor	Number of rows per ear	1000-kernel weight (g)	Plant height (cm)	Anthocyanin	Chl a	Chl b	Carotenoids
<b>Drought stress (evaporation from the pan, mm)</b>							
60	15.9	254.3	196.8	0.15	0.69	0.26	0.23
120	15.2	240.4	180.7	0.18	0.52	0.24	0.20
180	12.5	203.5	156.2	0.23	0.36	0.21	0.17
LSD 5%	2.2	37.0	12.5	0.014	0.06	0.021	0.038
<b>Hydrogel polymer (kg/ha)</b>							
0	14.1	228.1	167.5	0.21	0.475b	0.232	0.213
75	13.9	227.9	169.8	0.20	0.478b	0.234	0.212
150	14.7	235.7	184.5	0.18	0.55ab	0.24	0.195
225	15.5	239.3	189.8	0.16	0.61a	0.25	0.191
LSD 5%	-	-	16.4	0.024	-	-	-
F-test	ns	ns			ns	ns	ns

**Table 2** continued

Factor	Nitrogen	Phosphorus	Potassium	GPX	CAT
<b>Drought stress (evaporation from the pan, mm)</b>					
60	1.61	0.20	0.44	19.9	0.014
120	1.47	0.19	0.42	22.6	0.016
180	1.36	0.18	0.35	27.8	0.024
LSD 5%	0.17	0.009	0.01	3.8	0.0011
<b>Hydrogel polymer (kg/ha)</b>					
0	1.53	0.196	0.42	24.4	0.0191
75	1.51	0.194	0.41	24.2	0.0194
150	1.46	0.191	0.39	22.8	0.018
225	1.43	0.189	0.39	22.3	0.017
LSD 5%	-	-	-	-	0.0013
F-test	ns	ns	ns	ns	

ns: Not significant, Chl a: Chlorophyll a, Chl b: Chlorophyll b, CAT: Catalase, GPX: Gayacol peroxidase.

### **Photosynthesis pigments**

Data analysis showed that drought stress had a significant effect on chlorophyll “a” and “b” and carotenoids in the leaves of maize plants; however, hydrogel polymer and its interaction with drought

stress had no significant effect on these characteristics (Table 1). By increasing the drought level, the contents of chlorophyll “a” and “b” and carotenoids in the leaves decreased. The reductions from the control to severe drought stress conditions for chlorophyll “a” and “b” and carotenoids were 47.8%, 19.2%, and 26.1%, respectively (Table 2).

Based on the analysis of variance in Table 1, drought stress and hydrogel polymer had a significant effect on anthocyanin content; however, their interaction was not significant (Table 1). Contrary to chlorophylls “a” and “b” and carotenoids, as the drought level increased, the amount of anthocyanin increased by about 34.7% from the control to severe stress conditions (Table 2). However, the application of hydrogel polymer, significantly decreased anthocyanin in the leaves of maize plants (Table 2).

## Discussion

Lack of sufficient water in the soil, can inhibit the growth, photosynthesis, and biochemical processes, leading to yield decline. In this study, it was found that one of the earliest effects of drought stress was the reduction in photosynthetic pigments in maize plants, including chlorophyll “a” and “b” and carotenoids in the maize leaves. Nayyar and Gupta (2006) and Cao *et al.* (2011) indicated that drought stress affects different physiological characteristics such as chlorophyll content in plants. Changes in photosynthetic pigments under drought stress, can cause changes in growth and productivity of crops.

The results showed that by increasing the drought level, CAT and GPX antioxidant enzyme activity increased. The adaptation of crop plants to lack of sufficient water in the soil can be accompanied by the accumulation of osmotic compounds, and an increase in the activity of antioxidant enzymes (Parida and Das 2005; Mirzaee *et al.* 2013; Saed-Moosavi *et al.* 2014). However, drought stress sometimes reduces and even stops the activity of some enzymes in the Calvin cycle of photosynthesis (Monakhova and Chernyadev 2002).

The results showed that drought stress influenced the N, P, and K content in the maize grains. By increasing the drought stress level, the amount of these elements in the grains decreased. Water influences photosynthesis and the uptake and utilization of mineral nutrients in plants. According to Sardans and Peñuelas (2012), lack of sufficient water in soil can reduce the absorption of nutrients. The decrease in nutrient uptake under drought stress conditions, can occur due to various reasons, such as the reduction of nutrient supply due to increased mineralization and reduced nutrient diffusion and mass flow in the soil (Sanaullah *et al.* 2012). Drought can also reduce the activity of enzymes

that are involved in the uptake of nutrients in the roots and in their assimilation (Christophe *et al.* 2011).

In this study, grain yield, biomass, and the number of kernels per row in the maize plants significantly decreased as drought stress increased. Drought stress due to changes in morphology, photosynthesis, and accumulation of dry matter in different parts of the plant reduces grain yield in maize (Gheysari *et al.* 2017). It is recognized that maize is sensitive to drought, especially during the reproductive phase and water deficit can reduce grain yield (Saseendran *et al.* 2014). The reduction of photosynthetic pigments ultimately reduces the amount of photosynthesis and this affects growth and grain yield. In addition, the reduction in nutrients uptake, as well as the occurrence of oxidative stress can reduce the grain yield.

During the depletion of available water, it is important to increase irrigation efficiency and water productivity of crops by reducing water loss. The use of chemical compounds, such as hydrogel, has a great potential to utilize the existing water in the soil (Grabiński and Wyziński 2018). Therefore, some methods are needed to improve the efficiency of water use in the soil. In this study, the application of hydrogel polymer had significant effects on the anthocyanin content, CAT enzyme activity, grain yield, biomass, the number of kernels per row, and plant height in maize plants. During drought stress, the application of hydrogel polymer mitigated the harmful effects of drought stress on grain yield, biomass, the number of kernels per row, and plant height in maize plants. The highest grain yield and biomass were obtained by the application of 225 kg/ha hydrogel polymer under both drought stress conditions. Researches has confirmed the effectiveness of superabsorbent application in mitigating drought stress in crops. When hydrogels are added to the soil, they absorb and retain water and nutrients, and then release them to plants. Thus, growth and yield could be improved with limited water supply (Yazdani *et al.* 2007). Apostol (2009) reported that seedlings of *Quercus rubra*, which were treated with hydrogel, had 80% greater root moisture than the untreated roots following transplanting and a desiccation period. Grabiński and Wyzińska (2018) indicated that the application of hydrogel had a beneficial effect on the grain yield in wheat and the maximum grain yield was obtained by using 30 kg/ha hydrogel.

## Conclusion

Drought stress reduced photosynthetic pigments, such as chlorophyll “a” and “b” and carotenoids, in maize leaves, the NPK content in the grains, the number of kernels per row, the number of kernel rows per ear, 1000-kernel weight, biomass, and grain yield. However, the application of hydrogel polymer (225 kg/ha) mitigated the harmful effects of drought stress on the number of kernels per row,

biomass, and grain yield. Drought stress increased the activities of antioxidant enzymes such as CAT and GPX, but the application of hydrogel polymer reduced CAT activity of in maize plants when exposed to drought stress. Therefore, the application of 225 kg/ha hydrogel polymer can be considered beneficial for maize and helps mitigate the harmful effects of drought stress.

### Funding

This work was supported by the Agricultural College, Shahrood University of Technology, Iran, through a research project fund (No. 31044/2).

### Conflict of Interest

The authors declare that they have no known conflict of interest with any individual or organization concerning the subject of this article.

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