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Role of hydrophilic polymer in enhancing maize yield and yield components under climate variability in Iran

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Abstract

Climate change and increasing drought frequency pose serious threats to maize (*Zea mays* L.) production in arid and semi-arid regions. Hydrophilic polymers (HPs), due to their high water absorption and retention capacity, represent a promising strategy to mitigate water stress and enhance crop resilience. This study evaluated the effects of seed coating with HPs on maize yield and yield components under variable climatic conditions in Yasuj, Iran, during 2022 and 2023. A randomized complete block design with five replications was implemented, comparing HP-coated seeds with untreated controls. Physiological traits—including leaf relative water content (LRWC), normalized difference vegetation index (NDVI), and photochemical reflectance index (PRI)—as well as root morphological characteristics and yield components were measured. Results demonstrated that HP application significantly increased root length (27.7%), root surface area (18.9%), LRWC, NDVI, and PRI compared to the control. Moreover, HP treatment enhanced leaf and root biomass, thousand-grain weight, and overall grain yield by an average of 2 t ha^{-1} (29%). Interaction analysis revealed that favorable climatic conditions in 2022 combined with HP application produced the highest yield performance, while drought in 2023 reduced trait values but HP still alleviated stress effects.

Keywords: Hydrophilic polymer, LRWC, maize, NDVI, PRI.

Abbreviations

HP: Hydrophilic polymer; LRWC: Leaf relative water content; NDVI: Normalized difference vegetation index; PRI: Photochemical reflectance index; DAS: Day after sowing.

Introduction

Climate change has emerged as one of the most critical challenges to global food security, particularly in arid and semi-arid regions including Iran, where limited water resources and irregular precipitation patterns are intensifying (Dehkordi and Shamsnia, 2020). Maize (*Zea mays* L.), as the third most important cereal crop worldwide after wheat and rice, plays a vital role in human nutrition, livestock feed, and industrial applications (FAO, 2020). However, maize productivity is highly sensitive to water availability, and drought stress significantly reduces yield and yield components, including grain number, grain weight, and biomass accumulation (Dehkordi et al., 2013a). In recent decades, innovative soil amendments have been introduced to mitigate the adverse impacts of water stress. Among them, HPs have attracted considerable attention due to their capacity to take up and hold substantial quantities of water compared to their weight, thereby improving soil moisture availability and reducing nutrient leaching (Rahmani et al., 2023; Dehkordi, 2018a). Application of HPs has been reported to enhance crop growth, increase water use efficiency, and stabilize yields under deficit irrigation conditions (Dehkordi, 2017). Dehkordi and Eslamian (2024) reported that combining mild deficit irrigation with the application of HP, which enhance plant water productivity, constitutes an effective strategy for optimizing navy bean grain yield and improving water use efficiency. Furthermore, studies conducted in different regions of Iran have demonstrated that HPs, when combined with appropriate irrigation strategies, can significantly improve maize yield and its components under water-limited environments (Saeidinia, 2024). Given the increasing frequency of drought events and the urgent need for sustainable water management in agriculture, evaluating the role of HPs in enhancing maize productivity under climate change scenarios is of paramount importance. The objective of this study is to assess the influence of seed coating with HPs on maize yield and its yield components under field conditions. The outcomes are expected to provide valuable insights into enhancing maize production efficiency and optimizing crop performance in practical agricultural systems. The utilization of HPs as an environmentally friendly and cost-effective technology represents a significant advancement in sustainable agriculture. This approach offers a promising strategy for optimizing agricultural systems and enhancing their resilience to the challenges posed by climate change.

Materials and Methods

Materials and experimental details

This study was conducted at 30°9′ N and 49°57′ E, at an elevation of 1800 m above sea level, in Yasuj, Kohgiloyeh and Boyerahmad Province, Iran. The regional climate is classified

as cold and arid mountainous, characterized by relatively moderate summers and cold winters. The annual precipitation averages nearly 220 mm, where mean seasonal temperatures vary between −5 °C in winter and 30 °C in summer. Since this study was conducted during the years 2022 and 2023, the amount of precipitation and the monthly average temperatures throughout the crop growth period were measured and are presented in Table 1.

Table 1. Precipitation and temperature during the maize growth period

	April	May	June	July	August	September	October	November	sum	mean
Precipitation (mm)										
2022	30	13.9	0.5	13.8	17.4	0.6	8.6	160.2	245	
2023	11.5	2.3	0.0	0.0	0.0	0.0	0.0	52.5	66.3	
Temperature (°C)										
2022	13.1	17.2	24.1	26.5	25.1	22.0	17.1	10.6		19.5
2023	16.1	18.9	25.2	27.2	26.3	23.7	18.6	11.3		20.9

Tillage was performed at a medium depth in conjunction with the application of phosphorus and potassium fertilizers. During spring, the field was leveled using a disk, and the nitrogen requirement was estimated based on soil reserves and crop demand. Nitrogen was supplied as urea at rates of 90 (kg ha^{-1}) in both years. Phosphorus was applied at 40 (kg ha^{-1}) during the two years of study as superphosphate, while potassium was applied at 90 (kg ha^{-1}) during the two years of study as K_2SO_4. Samples of soil were taken from a depth of 0.25 to 0.35 m. Overall, the availability of NPK nutrients in the soil was classified as moderate. The physico-chemical characteristics of the studied soil are presented in Table 2, while the chemical composition of the irrigation water is summarized in Table 3.

Table 2. The physical and chemical characteristics of the soil

P (mg kg^{-1})	K (mg kg^{-1})	N (mg kg^{-1})	pH	Carbon content (%)	EC ($dS.m^{-1}$)	Soil texture	Size of the soil particles (%)		
							Sand	Silt	Clay
210	280	15.40	7.4	1.1	4.15	Loam	34	44	22

Table 3. The chemical characteristics of the irrigation water

EC ($dS.m^{-1}$)	Na ($meq.l^{-1}$)	Ca ($meq.l^{-1}$)	Mg ($meq.l^{-1}$)	SAR
1.0	5.0	4.0	2.1	2.9

Soil mineral nitrogen content was analyzed through the colorimetric technique. The ammonium form of nitrogen was measured with the Nessler reagent, while nitrate nitrogen was quantified using phenol 2.4-disulfonic acid. Potassium and phosphorus concentrations were assessed using the Mehlich III assay (Mehlich, 1984). Soil pH level was measured with a 1 M

KCl solution. Finally, soil organic carbon content was determined according to the Tjurin method (Rasovsky et al., 2023). Maize planting was conducted on April 01 in both years using a four-row seed planter. The experimental design was arranged as a randomized complete block with five replications. The control treatment (without HP) and the HP treatment were sown in six separate rows. The row spacing was 0.75 m, for every plot measuring 16 m in length, resulting in a total plot area of 60 m² (3.75 × 16 m). Preventive actions against crop diseases and harmful pests, as well as weed management, were implemented according to their incidence and the crop growth stage, thereby ensuring standardized and comparable field management practices across treatments. The average daily reference crop evapotranspiration (ET_o) was calculated using the Penman–Monteith method (Allen, 1998), based on meteorological data obtained from the Yasuj weather station located near the experimental site. Crop water requirement, represented by crop evapotranspiration (ETc), was calculated by multiplying ET_o by the crop coefficient (Kc) (Allen, 1998). The amount of applied irrigation water during the vegetative stage, designed to meet 100% of the ETc demand, was computed according to the equation below (Satriani et al., 2018; Allen, 1998):

$$AIW = \left(\frac{SWD+ETc}{Ea}\right) \quad (1)$$

where

AIW: applied irrigation water (mm), SWD: soil water deficit from the previous day (mm day^{-1}), ETc: crop evapotranspiration (mm day^{-1}), Ea: application efficiency (%).

Soil water content was measured using a multiplexing time domain reflectometry (TDR) system (HandiTrase Soilmoisture Meter with FCT Probe, model 6085K3, USA). The TDR system was remotely controlled by a computer. At the midpoint of the block rows, twelve TDR waveguides, each 40 cm in length, were installed vertically at soil depths ranging from 5 to 40 cm. Because the soil surface layer is highly sensitive to soil water fluctuations, the waveguides were positioned below the first 5 cm of soil to ensure proper insulation and measurement accuracy (Satriani et al., 2018). The maize (*Zea mays* L.) hybrid SC704 was used in the experiment. This cultivar is drought-tolerant and well-suited for cultivation in tropical regions. It was developed and introduced by the Agricultural Research Center of Safi-Abad Dezful, Khuzestan Province, Iran. The HP Super-AB-A-500 was utilized in this study (Table 4). This polymer, produced as white granular powder, is manufactured by Rahab Resin Co. under the product license of the Iran Polymer and Petrochemical Institute (Rahab Resin Company, Tehran, Iran). Chemically, this HP is a tripolymer composed of acrylamide, acrylic acid, and potassium acrylate. Maize seeds were processed with the Aquaholder®Seed coating technology

(developed by the knowledge-based company Pishgaman Development of Agricultural Plants, Karaj, Iran).

Table 4. The characteristics of Super-AB-A-500 polymer (Rahan Resin Co, 2016)

Characteristics	Super-AB-A-500 polymer
Shape	white granular powder
pH	7
Density	620±40 ($gr.l^{-1}$)
Specific weight	650 ($gr.l^{-1}$)
Water Holding Capacity at PF1	150 ($l.kg^{-1}$)
Maximum stability in soil	7-10 (year)
Practical capacity of water uptake	400 ($g.g^{-1}$)

Harvesting operations and measurements

In each experimental year, growth performance under separate treatments was evaluated in two rows, each 12 meters in length (with an area of 9 m^2), to quantify the number of germinated plants. In both years, this assessment was conducted on day 31 after sowing (DAS), corresponding to the six-leaf stage. At this time, a sample of 12 plants from each treatment was harvested to quantify leaf and root biomass. Soil residues were cleared by hand using a gentle stream of lukewarm water, after which the root and leaf system weights of every plant were measured. For the collection of maize ears at full maturity, the same plot area within each replicate was utilized. The harvested samples were subjected to laboratory analyses to determine parameters related to the thousand-kernel weight using the Numigral I seed counter (manufactured by Chopin, France), and the specific weight of maize kernels was determined using the Bastak HECTOLITERS 7000 device. Experimental plots were harvested on November 6 in both years at full maturity using the Lovol GV100 combine harvester (manufactured by Weichai Lovol, China). Following harvest, the overall grain yield per hectare was computed. Following separate harvests for all plots, the grain yield was measured and recorded using precise portable scales. In addition, supplementary root system assessments—including root surface area, volume, and length—were performed using the RhizoVision Explorer platform for digital image analysis (USA), specifically designed for measuring roots of various shapes. On day 50 after sowing, ten representative maize plants from each treatment were manually harvested to a depth of 0.25–0.35 m and transported to the laboratory under chilled conditions using a portable refrigeration unit. Soil residues were carefully washed away manually with a gentle stream of lukewarm water, after which the root system was detached using a specialized blade. Subsequently, every plant was individually scanned and analyzed to accurately evaluate both quantitative and qualitative root traits. NDVI and PRI were measured

during both growing seasons, respectively on days 50 and 70 after sowing. Measurements were conducted between 9:00 a.m. and 2:00 p.m. local time in Yasuj under full sunlight conditions without cloud cover. For this purpose, ten maize plants were randomly sampled from every treatment group. Subsequently, six individual measurements were taken on the flag leaf of every selected plant. Data recording was performed using the PlantPen NDVI & PRI device (manufactured by PSI, Photon Systems Instruments), which is equipped with integrated algorithms for calculating standard spectral indices and enables precise calculation of these parameters (Carlson and Ripley, 1997; Gamon et al., 1992; Rasovsky et al., 2023):

$$NDVI = (RNIR - RRED)/(RNIR + RRED) \quad (2)$$

$$PRI = PRI = (R531 - R570)/(R531 + R570) \quad (3)$$

LRWC was determined for both years. From each treatment, six fully developed upper leaves were collected; these leaves were immediately sealed in airtight packages and stored in a portable refrigerator. Upon arrival at the laboratory, fresh weight (FW) was determined by immediately weighing the samples. Subsequently, to achieve full turgidity, the samples were hydrated for a period of 5 hours under ambient laboratory conditions of temperature and light. After completion of the hydration period, the samples were taken out of the water, and surface moisture was carefully blotted using filter paper; thereafter, the turgid weight (TW) of the samples was recorded following the hydration period. The samples were then placed in small laboratory containers and oven-dried (AZ/OV53A model, manufactured by AZOTECH, Iran) at 85 °C for 24 hours. After cooling in a sealed glass chamber, the dry weight (DW) of the samples was determined following the oven-drying procedure. The LRWC was derived from the following formula (González and González-Vilar, 2001):

$$LRWC\ (\%) = [(FW - DW)/(TW - DW)] \times 100 \quad (4)$$

Statistical analysis

Data analysis was performed using SPSS software, version 26.0. Analysis of variance (ANOVA) was employed to assess differences among the treatments. A probability level of $p<0.05$ was considered statistically significant.

Results

The trend of climatic conditions differed across the two experimental years (Table 1), exerting a significant impact on the observed maize parameters. Severe drought at the time of sowing in 2023 markedly affected maize germination and seedling establishment. However,

this adverse factor was less pronounced in 2022. Variations in climatic trends were also evident during subsequent growth stages. Intense drought and elevated temperatures in 2023 likely contributed to the reduction of selected maize traits compared with 2022.

HP effects on root morphometry: length, volumetric, and areal dimensions

The analysis of maize root morphological traits revealed that seed coating with HP exerted a notably positive effect, although statistical significance was observed only for root length and root surface area. Figure 1 showed that the root length in the HP-treated plants was 41 cm (equivalent to 27.7%) greater than that of the control treatment. Furthermore, root volume increased under HP utilization; although, the difference between the treated and control groups was not statistically significant (0.2 cm^3; 11%). Maize treated with HP exhibited a larger root surface area, with an increase of 11 cm^2 (equivalent to 18.97%) compared to untreated samples.

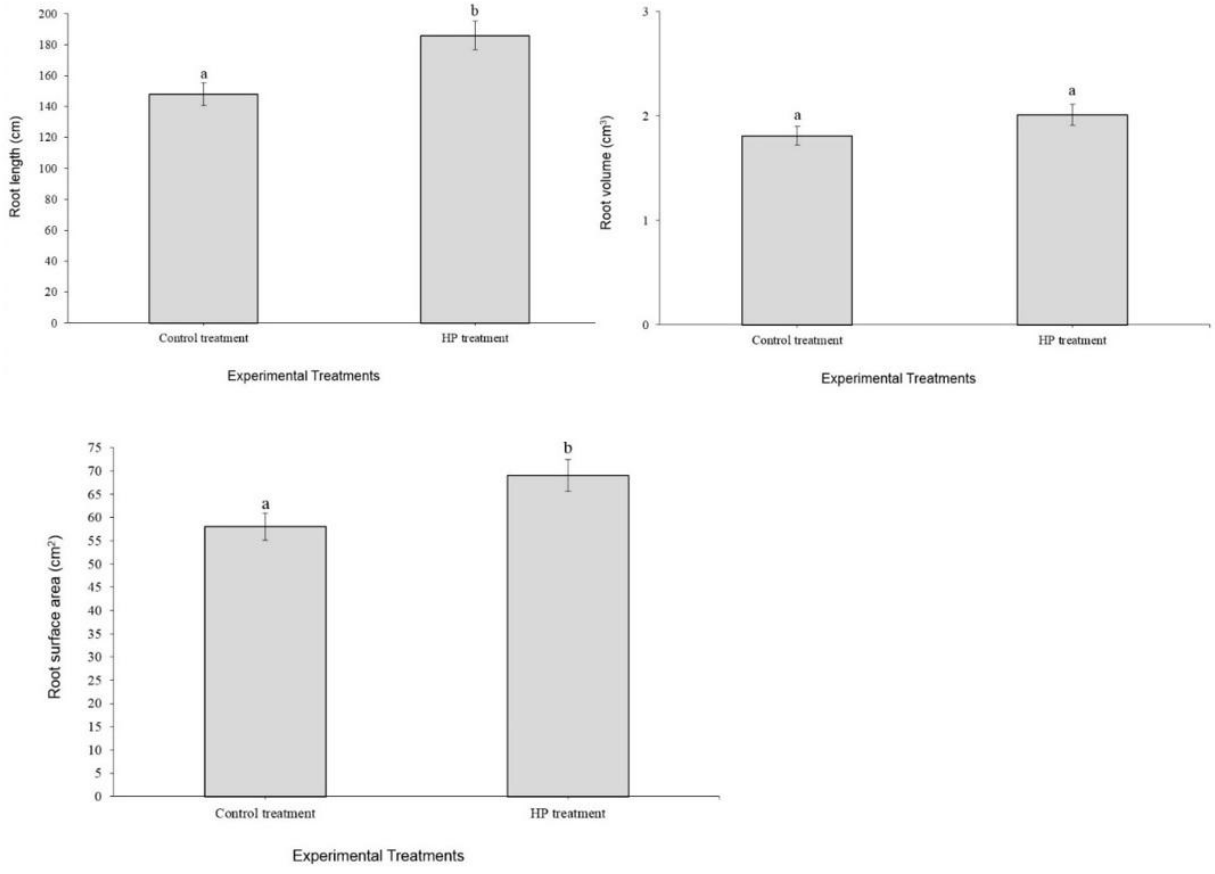


Figure 1. Root surface area, root volume, and root length of maize under different treatments. Different lowercase letters indicate statistically significant differences at the probability level of $p < 0.05$.

Effects of HP on LRWC, PRI, and NDVI

The results of the study demonstrated that HP exerted a considerable positive impact on the root system and soil properties, which has been well reported. However, information regarding their effects on the aerial organs of plants remains limited. Findings from this experiment revealed that HP had a significant influence on LRWC and spectral indices of maize. As shown in Figure 2, statistically significant differences were observed between the HP-treated and control groups in LRWC values as well as in the PRI and the NDVI. These results indicate that the application of HP affects not only the root system but also physiological processes associated with aerial plant organs.

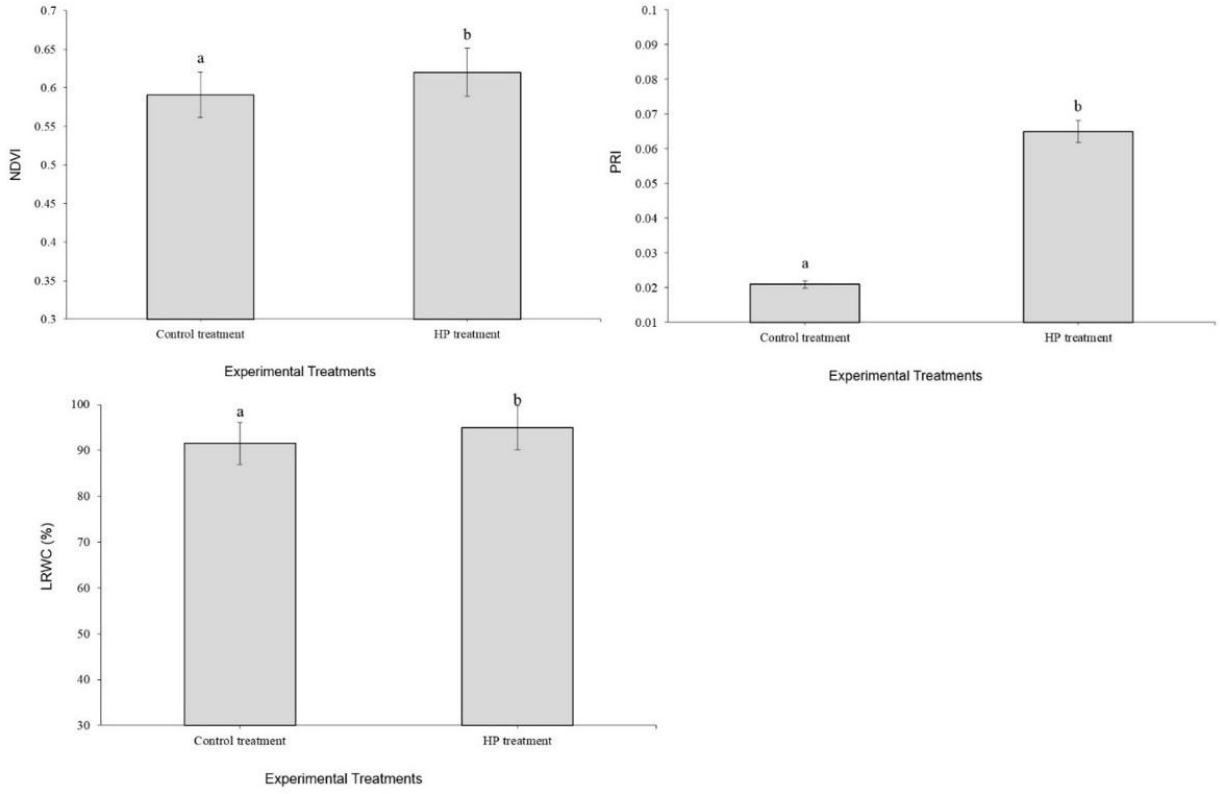


Figure 2. LRWC, NDVI, and PRI of maize under different treatments. Different lowercase letters indicate statistically significant differences at the probability level of $p < 0.05$.

Effects of HP on grain yield and other yield components

The results indicated that seed coating with HP had a significant impact on grain yield and ear number per plot (Figure 3). In addition, statistically significant differences were observed for two traits measured during the growth period, namely leaf weight and root weight. Comparison of treatments showed that HP application markedly increased leaf weight (by an average of 1.4 g, equivalent to 56%) and root weight of maize (by an average of 0.59 g,

equivalent to 35%) (Figure 4). Although no significant differences were found between treatments in plant density per plot and grain specific weight, a significant difference was observed in thousand-grain weight (Figure 5). Thus, application of HP resulted in a marked increase in this trait relative to the control. It can be inferred that this factor, in conjunction with the other results mentioned, contributed to a significantly higher grain yield in HP-treated maize (by an average of 2 t ha^{-1}, equivalent to 29%) compared to the control (Figure 3).

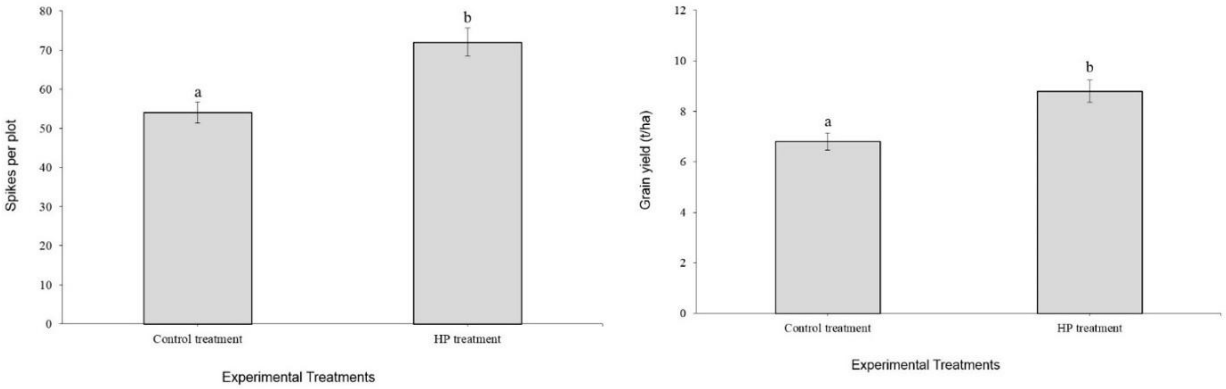


Figure 3. Grain yield and spikes per plot of maize under different treatments. Different lowercase letters indicate statistically significant differences at the probability level of $p < 0.05$.

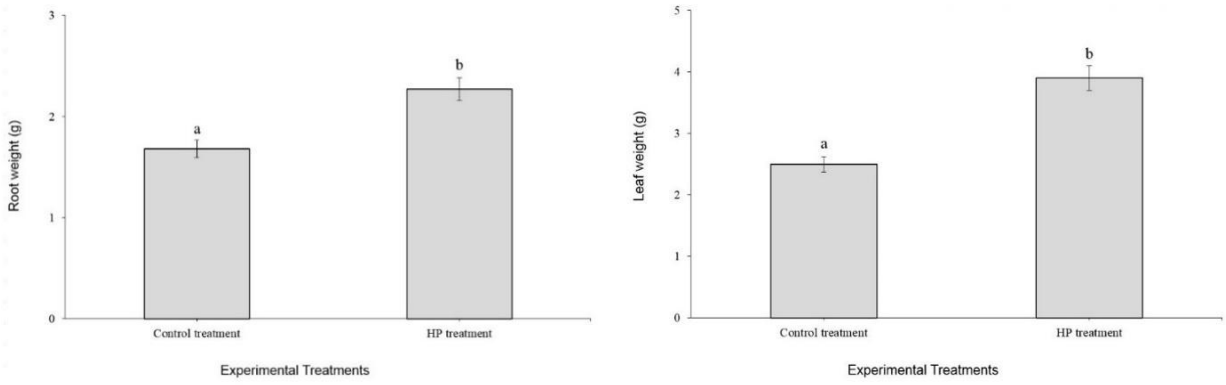


Figure 4. Root and leaf weights of maize under different treatments. Different lowercase letters indicate statistically significant differences at the probability level of $p < 0.05$.

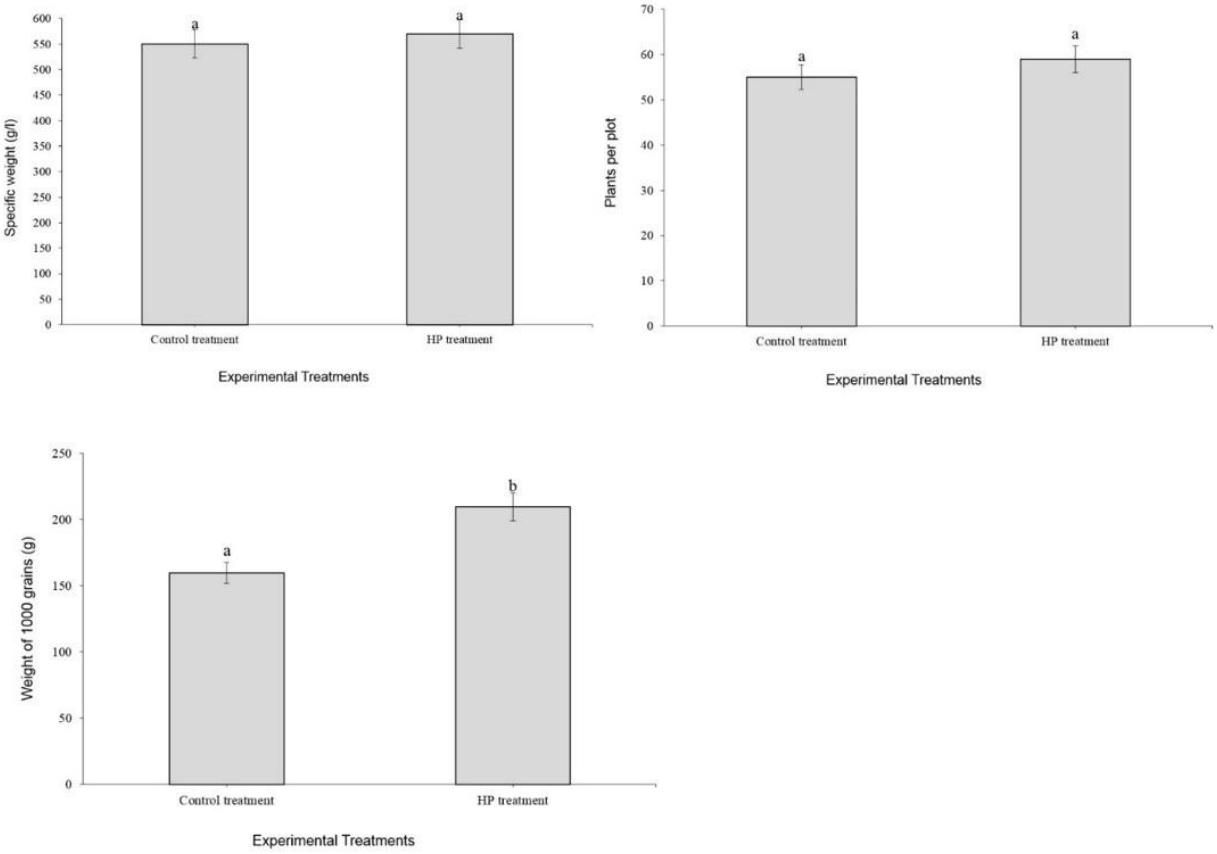


Figure 5. Specific weight, plant density per plot, and thousand-grain weight of maize under different treatments. Different lowercase letters indicate statistically significant differences at the probability level of $p < 0.05$.

Interaction effects between year and experimental treatments on maize characteristics

The general interaction impact between year and experimental treatments was statistically significant for grain specific weight, thousand-grain weight, root weight, and leaf weight. As illustrated in Figure 6, the highest values for most traits were observed in the interaction between the year 2022 and the HP treatments, which exhibited varying levels of statistical significance compared to other combinations. In contrast, the combination of the year 2023 with unfavorable climatic conditions, including drought, elevated air temperatures, and uncoated seeds, led to the minimum values for most characteristics. These findings indicate that more favorable environmental conditions in 2022, characterized by higher rainfall and milder temperatures, together with the application of HP, produced substantial positive effects on maize growth characteristics and yield performance.

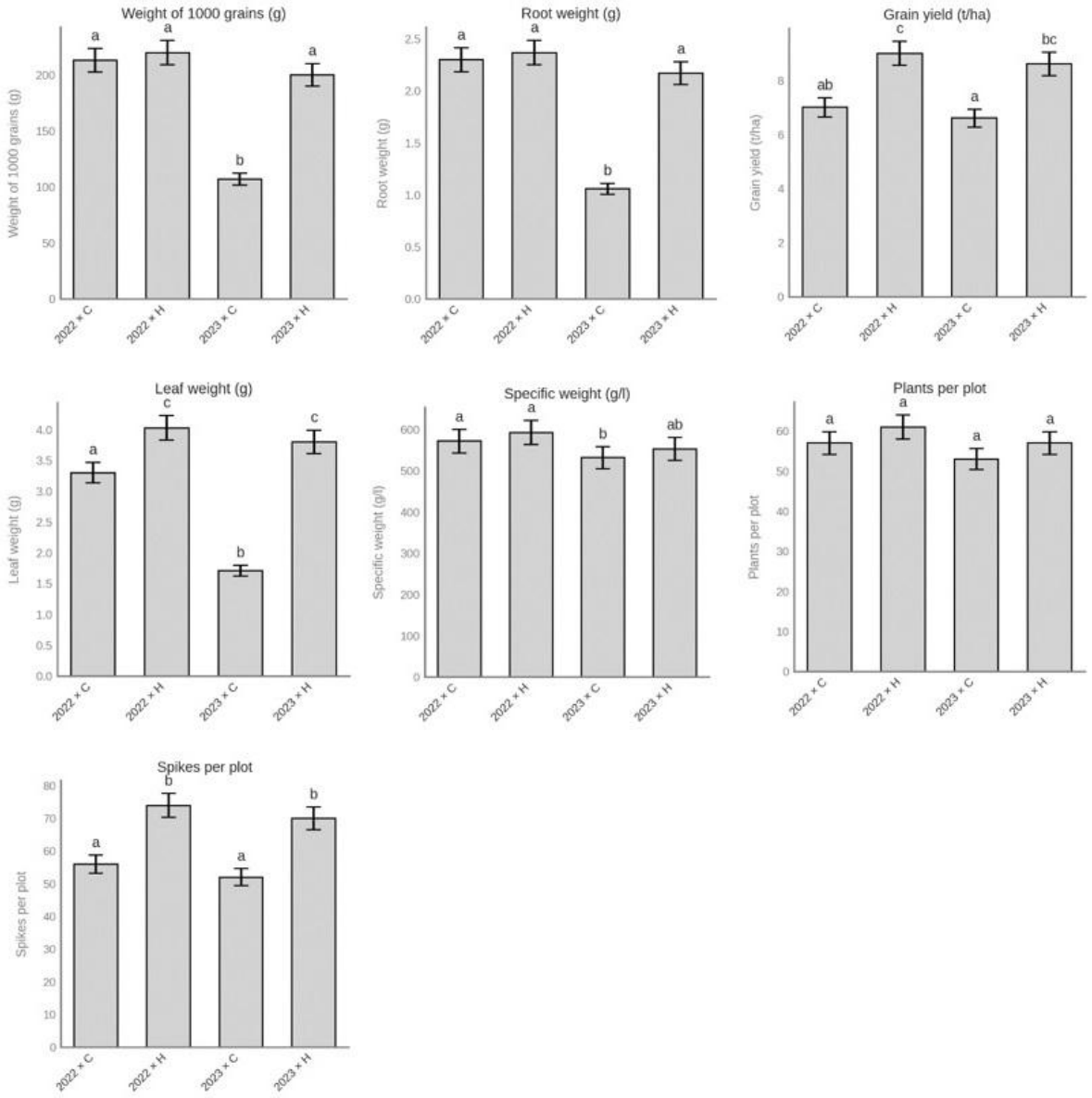


Figure 6. Interaction effects between year and experimental treatments. Different lowercase letters indicate statistically significant differences at the probability level of $p < 0.05$. C: represents the control treatment (without HPs); S: represents the HP treatment

Analysis of correlation coefficients

Analysis of correlation coefficients was conducted separately for every treatment to highlight the constructive effects of HP on the interrelationships among maize traits. This is of great importance, as positive correlations among yield components essentially determine overall crop production. As shown in Table 6, consistently high positive correlations were recorded in maize with HP-coated seeds. In contrast, the control treatment exhibited weaker correlations compared to the HP treatment (Table 5).

Table 5. Interdependence of maize yield components with the control treatment

	Grain yield	Plants per plot	Spikes per plot	Thousand-grain weight	Specific weight
Grain yield	1.00	0.76	0.25	0.78	0.74
Plants per plot	0.76	1.00	0.48	0.72	0.41
Spikes per plot	0.25	0.48	1.00	0.51	0.11
Thousand-grain weight	0.78	0.72	0.51	1.00	0.70
Specific weight	0.74	0.41	0.11	0.70	1.00

Table 6. Interdependence of maize yield components with the HP treatment

	Grain yield	Plants per plot	Spikes per plot	Thousand-grain weight	Specific weight
Grain yield	1.00	0.85	0.47	0.89	0.78
Plants per plot	0.85	1.00	0.69	0.85	0.89
Spikes per plot	0.47	0.69	1.00	0.59	0.88
Thousand-grain weight	0.89	0.85	0.59	1.00	0.81
Specific weight	0.78	0.89	0.88	0.81	1.00

Therefore, it can be conclusively confirmed that the application of HP plays a significant role in maize production and effectively enhances the relationships among its yield components.

DISCUSSION

Maize is regarded among the most important and high-yielding cereal crops worldwide. In addition to its pivotal role in human and animal nutrition, maize also serves as a valuable source for biofuel production. However, global climate change in recent decades has intensified both abiotic and biotic stresses, posing serious threats to maize production across different regions of the world. It is projected that the frequency of severe and unpredictable climatic events will increase substantially in the future. These circumstances underscore the urgent need to develop and implement effective adaptation strategies. One innovative approach in this regard is the use of HP through seed coating. Due to their high capacity for water absorption and retention, HP can alleviate the adverse impacts of drought in maize production (Dehkordi, 2018c; Sheoran et al., 2022; Chávez-Arias et al., 2021; Rasovsky et al., 2023). Therefore, the primary objective of this study was to investigate the impact of seed coating with HP on alleviating drought stress and improving maize performance under variable climatic conditions. Climatic conditions varied considerably across the experimental years, which influenced the outcomes of this study. Several researchers have confirmed the strong dependence of crop productivity on climatic factors (Omoyo et al., 2015). Among these, drought is recognized as one of the most critical environmental stresses, typically resulting from fluctuations in temperature, light intensity, and reduced precipitation. The stage of plant development, along with the intensity and length of drought, plays a crucial role in determining how plants respond

to this stress. (Shamsnia and Dehkordi, 2020; Seleiman et al., 2021). It is well recognized that seed germination and proper seedling development are critical factors in determining final crop yield. At these stages, water stress is considered the most important factor contributing to yield reduction (Dehkordi et al., 2013b; Zvinavashe et al., 2021). The findings of the present study revealed that the application of HP had a significant effect on leaf and root biomass of young plants, with these traits showing substantial increases under HP treatment. This result has also been reported by other researchers, who demonstrated that HP-treated plants exhibited greater resilience to drought stress compared to untreated controls (Zinivand et al., 2020; Norodinvand et al., 2019; Pačuta et al., 2021). Nevertheless, drought occurring during later growth stages led to reductions in leaf and plant dimension, a phenomenon attributed to declined transpiration and limitations in the photosynthetic process (Rasovsky et al., 2023). Distribution of root diameter and length are key indicators for describing and comparing root systems. These traits can be identified either through microscopic assessments, which is inherently time-consuming, or through computer-based analysis, which offers higher efficiency but remains highly responsive to scanning conditions (Bouma et al., 2000). Results obtained from the RhizoVision Explorer software indicated that treatment with HP significantly increased root length. A similar trend was observed in root volume and surface area, although these increases were not statistically significant. Furthermore, in interaction with the experimental year, HP exerted positive and, in some cases, significant effects on leaf and root biomass of maize during early growth stages. This effect was likely due to greater water availability to seeds as a result of HP coating (Gubišová et al., 2021; Dehkordi and Seyyedbouveir, 2013). At advanced growth stages, drought stress can reduce the duration of leaf greenness by promoting accelerated senescence (Dehkordi, 2020). This phenomenon directly affects yield components, including sterility, grain shrinkage, and kernel abortion, ultimately leading to a reduction in the harvest index (Dehkordi, 2018b; Araus et al., 2012). Based on the findings of this study, no significant differences were observed between most yield and yield component traits of maize under HP treatment in 2023 and the control treatment in 2022, despite unfavorable climatic conditions (drought and elevated temperature). These findings indicate that while HP predominantly affects soil characteristics and root system traits, it may also impact other physiological processes related to yield formation and its components in maize. Several researchers have emphasized the necessity of evaluating the effects of HP in relation to soil variables and plant parameters (Dehkodi et al., 2023; Malik et al., 2023). Accordingly, in this study, spectral indices were analyzed using non-destructive methods, along with the assessment of relative leaf water content. Measurement of the PRI can serve as a tool for detecting water stress during the early

stages of plant growth; however, its effectiveness is dependent on light conditions. Structural changes in leaves and pigments under water stress alter reflectance, thereby affecting PRI values. Numerous studies have demonstrated that PRI is influenced by structural growth characteristics as well as developmental variables such as growth stage and leaf area index (Cheng et al., 2013; Alonso et al., 2017; Gamon, 2015; Rasovsky et al., 2023). The results of the present study showed that PRI values were significantly higher under HP treatment compared to the control. In addition, NDVI values were also significantly greater in HP-treated plants, indicating the positive impact of these polymers on the physiological status of the crop. The NDVI is directly associated with the photosynthetic activity of growing plants. This index exhibits a significant positive correlation with leaf chlorophyll content. Moreover, NDVI values can be markedly influenced by factors such as crop leaf area, nitrogen levels, chlorophyll concentration, and tissue water content. The findings of this study confirmed these relationships, as leaves treated with HP exhibited significantly higher LRWC. In ecophysiology, LRWC is widely recognized as an indicator for describing the degree of water saturation in plant leaves. It serves as a reliable indicator of plant water status and is widely recognized as a surrogate parameter for evaluating the physiological consequences of cellular water deficit (Farinas et al., 2019; Zhou et al., 2020; Din et al., 2017; Rasovsky et al., 2023). In this study, correlation analysis was conducted, as increases in crop yield are generally the result of positive relationships between yield and its components. From a statistical perspective, correlation is a simple yet practical measure that describes the degree of interdependence among observed variables. To evaluate the effects of HP seed coating on maize yield components, correlation analyses were conducted separately for each treatment. As presented in Tables 5 and 6, the interdependence among yield components was considerably higher under HP treatment compared to the control. Consequently, it can be concluded that HP treatment significantly enhanced maize grain yield in this study, which is consistent with the findings of previous researchers (Mahesh et al., 2022; Rasovsky et al., 2023). The results of this study revealed that the effect of HP on maize growth was evident from the earliest developmental stages, with a significant difference observed even in root length and root surface area. In addition, higher values of PRI, NDVI, and LRWC were recorded under HP treatments, showing significant increases compared to the control. These findings suggest that seed coating with HP exerts a stimulatory impact on maize growth, particularly during the earliest and most sensitive stages of development, ultimately leading to yield improvement. The application of this method can serve as an effective strategy for protecting crops against climatic fluctuations, especially

in regions prone to prolonged droughts and elevated temperatures. Nevertheless, considerable scope remains for further research, particularly regarding the impact of HP on crop quality and plant developmental processes, which may uncover new dimensions of the effectiveness of this technology.

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This study was not supported by any funding organization.

Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request (Corresponding Author's Email address: korkori@iau.ac.ir or davood_kh70@yahoo.com).

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