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# Improving growth and establishment in some cool-season plants under drought conditions using water-superabsorbent polymer

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**Abstract**

**Objective**: Approximately one-third of the world's land faces a precipitation shortage, and half of it receives annual precipitation of less than 250 mm. The objective of this study was to evaluate the impact of varying rates of superabsorbent polymer (A-200) on the establishment and seedling growth of selected cool-season plants under drought conditions.

**Methods**: The experiments were conducted as a factorial arrangement with three replications at the research station of the College of Agriculture and Natural Resources, Razi University, Iran. In the field experiment, factors included cool-season plant species and anionic superabsorbent polymer (0, 2, 4, 6, and 8 grams per square meter), and in the pot experiment, the factors included cool-season plant species, super-absorbent polymer (0, 0.2, 0.4, and 0.8 grams per kilogram of soil), and water-deficit stress [favorable (3-day irrigation interval) and stress (6-day irrigation interval)]. Cool-season plants included safflower, canola, and alfalfa.

**Results**: The results showed that with increasing the superabsorbent polymer rate, seedling dry weight, plant height, and emergence percentage and rate were significantly increased. Increasing the irrigation interval decreased these characteristics. The superabsorbent polymer reduced the negative effect of water deficit stress.

**Conclusion**: A superabsorbent polymer amount of eight grams per square meter is recommended for a higher seedling establishment in the studied safflower, canola, and alfalfa plants.

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## Introduction

Water scarcity is the main limiting factor for agricultural production in the world. Hydrogels are special polymer materials that are capable of absorbing a large amount of water per gram of dry matter in the first contact with water due to the presence of a hydrophilic component in the structure of the main network chains (Sannino *et al*. 2004). According to Tohidi-Moghaddam *et al*. (2009), in the clay loam soil texture, Stocosorb application of 0.4% compared to 0.2% increased pine (*Pinus halepensis*) survival. Sivapalan (2001) investigated the effect of superabsorbent polymers in coarse soils on soybean growth and reported that superabsorbent treatment had higher dry matter production and plant height compared to the untreated treatment. In a study, water superabsorbent polymer increased the shoot and root weight in *Pinus pinaster* by 8.61% and 13.70 %, respectively, compared to the control (Liu *et al*. 2013). Su *et al*. (2017) reported that super-absorbent polymer coating improved the percentage and energy of seed germination, seedling emergence, and growth in *Caragana korshinskii.* According to Tomadoni *et al.* (2020), an 80% increase in the fresh weight of lettuce, grown in a bed with 5% hydrogel compared to the control bed, was observed after seven days under drought conditions (Tomadoni *et al*. 2020). Mazloom *et al*. (2020) indicated that maize was taller and had higher biomass under the application of lignin hydrogel and sodium polyacrylate hydrogel compared to the plants with no hydrogel application. In addition, higher biomass and leaf relative water content were observed under severe water deficit stress compared to the treatment with no hydrogel. In a study, the effect of micron-sized metal-binding hydrogel particles on seed germination traits of Australian metallophyte plants was assessed. The highest germination percentage and higher radicle growth under limited water conditions were observed when metal-binding hydrogel particles were applied. This indicates that these hydrogel particles were able to supply moisture to the seed and improve seed germination traits (Guterres *et al*. 2013). Dexters and Miyamoto (1995) reported that the application of superabsorbent polymers increased germination, emergence, and growth of sugar beet plants. According to Armandpisheh *et al*. (2011), application of zeolite under drought conditions increased emergence percentage, average daily emergence, and seedling establishment percentage in canola (*Brassica napus* L.). Kargar *et al*. (2017) reported that the superabsorbent application on the sapling of *Ulmus pumila* under drought stress improved their growth traits. In *Eucalyptus dunnii*, the increase in the crown diameter and the plant height was observed due to the application of the water-absorbent polymer (Navroski *et al*. 2016).

Due to the problem of the establishment of plants with small seeds, the percentage of emergence in the field needs to be increased. This is possible with methods such as maintaining moisture around the seeds using water-superabsorbent. The purpose of this study was to determine the effect of water-superabsorbents on the establishment and growth of seedlings of some cool-season plants under drought conditions.

## Materials and Methods

### *Field experiment*

This study was conducted as a factorial experiment, based on a randomized complete block design with three replications at the Agricultural and Natural Resources Campus of Razi University, Kermanshah, Iran in 2014 (Longitude 47° and 9' E, Latitude 34° 21' N, 1319 meters above sea level, average rainfall of 450-480 mm, clayey silty soil texture). The factors included anionic water-superabsorbent polymer (0, 2, 4, 6, and 8 g/m$^2$) and cool-season plant species (safflower, canola, and alfalfa). Cool-season plants were sown on March 10, 2014. The plot size was one meter by one meter, and the distance between the two plots was half a meter. Planting densities for safflower, canola, and alfalfa were 10, 50, and 83 plants per m$^2$, respectively. The superabsorbent used in this study was the A-200 superabsorbent. The seeds and water-superabsorbent polymer were planted together in the planting rows. Weeds were controlled by hand. There were no symptoms of pests and diseases in the field. Surface irrigation was used in this experiment.

### *Pot experiment*

The research was carried out as a factorial experiment, based on a completely randomized design with three replications. Factors included cool-season plant species (safflower, canola, and alfalfa), anionic water-superabsorbent (0, 0.2, 0.4, and 0.8 g/kg soil), and water deficit stress (favorable 3-day irrigation interval and water deficit stress with 6-day interval). The irrigation interval was selected based on a pre-experiment. In this way, several pots were placed in the greenhouse before applying the treatments, and by observing the symptoms of the plant and the soil appearance, favorable and water deficit stress intervals were determined. At each irrigation event, pots were irrigated to the extent that the whole soil was wetted and drainage was minimized. Therefore, the soil of the pot was irrigated up to the point of field capacity each time. Ten seeds of canola, safflower, and alfalfa plants were sowed in pots of 7 cm in diameter and 7.5 cm in depth and containing 300 g of soil at 1, 2, and 1 cm depth, respectively. Three weeks after planting, several traits were measured.

### *Measured traits*

Seedling height, seedling dry weight, and seedling emergence percentage were measured in both the field and the pot experiments. Seedling emergence rate was measured in the pot experiment only. Plant height and seedling dry weight were measured using five plants per plot. To measure dry weight, samples were placed in an oven for 72 hours at a temperature of 75 °C. The percentage of emergence was calculated with Ellis and Roberts's (1981) equation. The rate of emergence was obtained by the following equation:

$$AVE = \frac{\sum Nt}{\sum t}$$

Where AVE is the seed emergence rate (number per day), ΣNt is the sum of the number of emerged seeds at time t, and Σt is the sum of times (days). Some of the physical and chemical properties of soil and water used in both studies are presented in Table 1.

**Table 1.** Physical and chemical properties of soil and irrigation water at the experimental site.

| **Soil** | | **Water (Ghamarnia *et al*. 2010)** | |
|---|---|---|---|
| Texture | Clayey silt | EC (µ ohs/cm) | 1000 |
| pH | 7.2 | pH | 7.10 |
| EC (ds/m) | 1.6 | TDS | 640 |
| OC (%) | 1.3 | Mg + Ca (meq/L) | 8.15 |
| N (%) | 0.8 | Na (meq/L) | 1.08 |
| P (ppm) | 10 | | |
| K (ppm) | 230 | | |

### *Data analysis*

After analysis of variance, the means were compared with Duncan’s multiple range test at a significance level of 0.05. The data were analyzed using MSTATC and SAS software, and Excel software was used for drawing graphs

## Results

### *Field experiment*

***Seedling height*:** Analysis of variance showed that the interaction of species with water-superabsorbent on seedling height was significant at the 5% level (Table 2). The use of water-superabsorbent of eight grams per square meter increased plant height about 0.38, 0.97, and 1.26 times compared to no water-superabsorbent use in safflower, alfalfa, and canola, respectively (Figure 1a). This reaction may be due to an increase in moisture content in the soil. Sivapalan (2001) reported that plant height was increased by the application of water-superabsorbent compared to the control. According to Tan *et al*. (2021), hydrogel improved the growth of *Brassica rapa* by maintaining moisture and reducing the leaching of nutrients, which is consistent with the results of the present study.

**Table 2.** Analysis of variance (mean squares) of the water-superabsorbent effect on some traits of cool-season plants in the field

| Source of variation | df | Mean squares | | |
|---|---|---|---|---|
| | | Seedling height | Seedling dry weight | Emergence percentage |
| Block | 2 | 0.22** | 30.09** | 3.19 |
| Plant species (P) | 2 | 238.94** | 473504.25** | 822.38** |
| Water-superabsorbent (W) | 4 | 18.66** | 26694.28** | 344.45** |
| W × P | 8 | 0.05* | 6032.52** | 26.08** |
| Error | 28 | 0.01 | 3.97 | 1.47 |
| Coefficient of variation (%) | - | 1.39 | 1.27 | 1.82 |

* and **: Significant at the probability levels of 5% and 1%, respectively.

***Seedling dry weight*****:** Analysis of variance showed a significant interaction of species with water-superabsorbent on the seedling dry weight (Table 2). The use of water-superabsorbent of eight grams per square meter increased seedling dry weight by 1.05, 3.31, and 3.02 times compared to the control in safflower, alfalfa, and canola, respectively. However, the relative increase in alfalfa was higher than in safflower and canola (Figure 1b). Khorram *et al.* (2003) reported that adding the superabsorbent polymer to the soil gradually shifts the absorbed water to the root of the plant, so the soil remains moist for a long time.

***Emergence percentage*****:** Analysis of variance showed that the interaction of species with the water-superabsorbent was significant for the percentage of emergence (Table 2). The use of water-superabsorbent of eight grams per square meter increased emergence by 0.38, 0.12, and 0.30 times compared to the control in safflower, alfalfa, and canola, respectively, but this increase was higher in safflower compared to alfalfa and canola (Figure 1c). The reason for the greater effect of water-superabsorbent on the percentage of safflower emergence is probably due to the bigger and higher food reservoirs of safflower seed than alfalfa and canola. In a study, water-superabsorbent increased seedling emergence and sapling establishment in *Haloxylon aphyllum* compared to the control (Rafiei 2010), which is in concordance with our results.

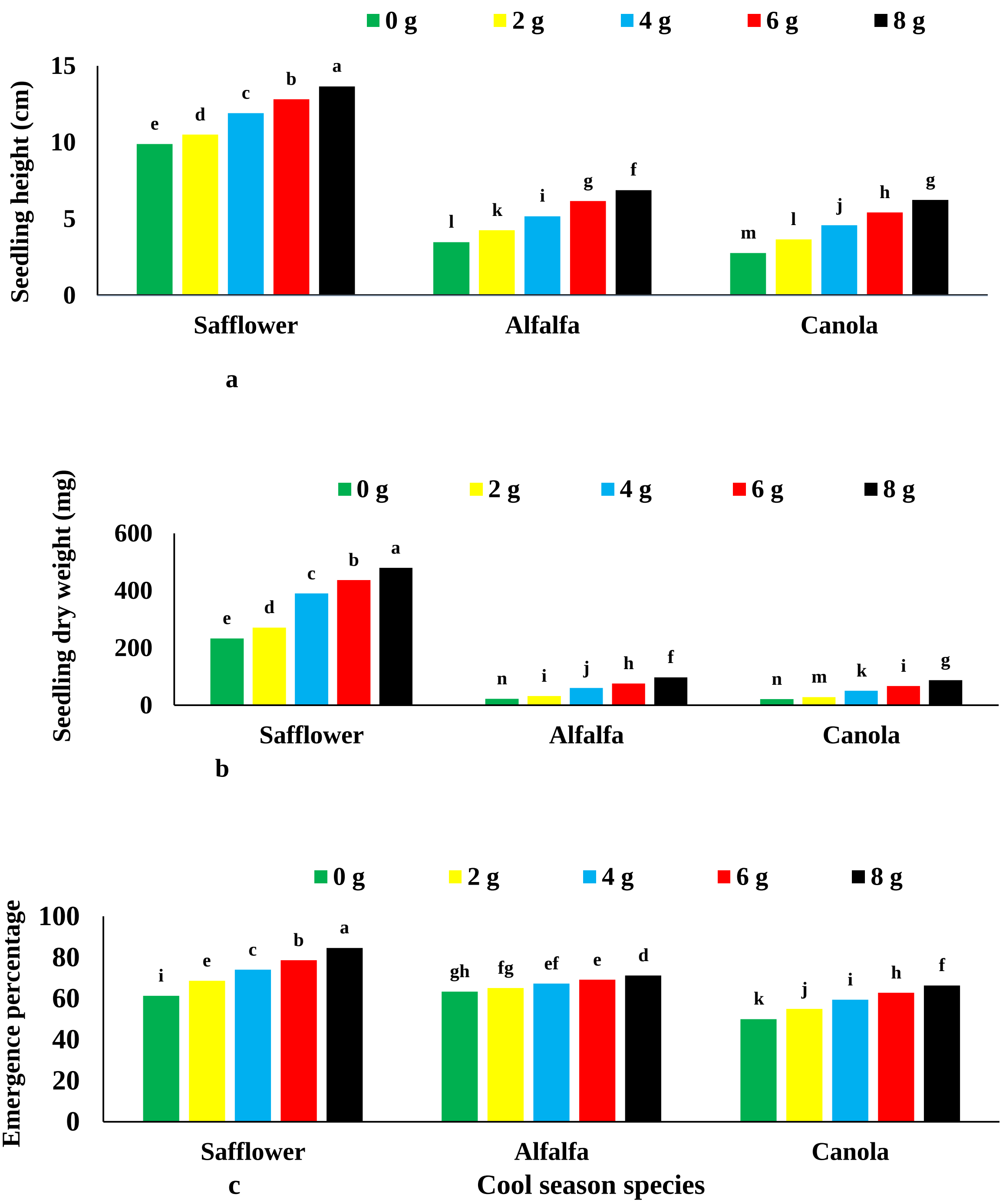


**Figure 1.** Effect of water-superabsorbent on seedling height (a), seedling dry weight (b), and emergence percentage (c) of cool-season species; 0, 2, 4, 6, and 8 are water-superabsorbent polymer rates of 0, 2, 4, 6, and 8 g per square meter of soil, respectively; Means with the similar letters were not statistically significant at the 0.05 probability level based on Duncan's multiple range test.

***Pot experiment***

***Seedling height***: Analysis of variance showed a significant interaction of species × water-superabsorbent and species × water deficit stress for seedling height (Table 3). The use of water-superabsorbent polymer increased the seedling height in all three studied plants. The use of water-superabsorbent polymer at a rate of 0.8 grams per kilogram of soil increased the plant height by 1.3, 1.6, and 1.6 times in safflower, alfalfa, and canola, respectively, compared to the control. It seems that the superabsorbent can absorb and retain a considerable amount of water after each irrigation time inside the pores, and as a result, the absorbed water is gradually consumed by the plant. In a study, hydrogel increased plant height in peas due to moisture retention and its absorption by the plant compared to the treatment without hydrogel (Iqbal *et al.* 2024), which is consistent with the results of this study. According to Jia *et al*. (2024), hydrogel increased the fresh weight of tobacco plants in dry conditions because it increased the relative moisture content of the leaf, which improved the stomatal condition and increased the photosynthetic capacity of the tobacco plant. They stated that another reason for increasing plant biomass with hydrogel was the reduction of reactive oxygen species caused by drought, which reduced damage to cell membranes. Part of the difference in plants in terms of response to superabsorbent was related to genetic variation.

Irrigation interval of 6 days decreased seedling height in alfalfa and canola (Table 4); however, no significant change was observed in safflower, indicating that safflower is more tolerant than alfalfa and canola to the water-deficit stress.

**Table 3.** Analysis of variance (mean squares) of the effect of water-superabsorbent and drought stress on some traits of cool-season plants in the pot experiment.

| **Source of variation** | **df** | **Seedling height** | **Seedling dry weight** | **Emergence percentage** | **Emergence rate** |
|---|---|---|---|---|---|
| Water deficit stress (W) | 1 | 4.59** | 1955.65** | 919.11** | 2.18* |
| Plant species (P) | 2 | 416.85** | 12501.36** | 442.72** | 8.18** |
| Water-superabsorbent (S) | 3 | 14.93** | 1758.39** | 2083.04** | 14.71** |
| P × W | 2 | 1.91** | 184.86** | 15.85 | 0.12 |
| S × W | 3 | 0.09 | 4.387* | 179.71** | 3.08** |
| P × S | 6 | 1.13** | 120.36** | 68.33 | 0.78* |
| W × S × P | 6 | 0.03 | 3.20* | 37.78 | 0.39 |
| Error | 48 | 0.10 | 1.3 | 29.66 | 0.30 |
| Coefficient of variation (%) | - | 5.08 | 2.94 | 6.71 | 8.11 |

*,**:Significant at the probability levels of 5% and 1%, respectively.

**Table 4.** Means for the effects of irrigation interval and water-superabsorbent polymer on seedling traits of safflower, alfalfa, and canola.

| Treatment | Seedling height (cm) | Seedling emergence rate (No/day) | Treatment | Seedling emergence percentage | Seedling emergence rate (No/day) | Treatment | Seedling height (cm) |
|---|---|---|---|---|---|---|---|
| P1S1 | 10.1c | 5.0d | I3S1 | 71.1c | 5.7d | P1I3 | 11.3a |
| P1S2 | 10.3c | 5.4d | I3S2 | 84.4b | 6.9bc | P1I6 | 11.54a |
| P1S3 | 12.3b | 6.6c | I3S3 | 84.4b | 6.5c | P2I3 | 4.0b |
| P1S4 | 13.1a | 7.8ab | I3S4 | 100.0a | 8.5a | P2I6 | 3.2c |
| P2S1 | 2.7g | 5.5d | I6P1 | 64.4d | 5.6d | P3I3 | 4.0b |
| P2S2 | 3.3f | 6.5c | I6P2 | 71.1c | 5.9d | P3I6 | 3.2c |
| P2S3 | 3.9e | 6.6c | I6P3 | 85.5b | 7.2b | | |
| P2S4 | 4.4d | 7.9ab | I6P4 | 87.7b | 7.4b | | |
| P3S1 | 2.8g | 6.6c | | | | | |
| P3S2 | 3.3f | 7.3b | | | | | |
| P3S3 | 3.9e | 7.4b | | | | | |
| P3S4 | 4.5d | 8.2a | | | | | |

P1, P2, and P3 are safflower, alfalfa, and canola, respectively; I3 and I6 are irrigation intervals of 3 and 6 days, respectively; S1, S2, S3, and S4 are water-superabsorbent polymer rates of 0, 0.2, 0.4, and 0.8 g per kg of soil, respectively; The means with similar letters in each column were not statistically significant at the 0.05% level based on Duncan's multiple range test.

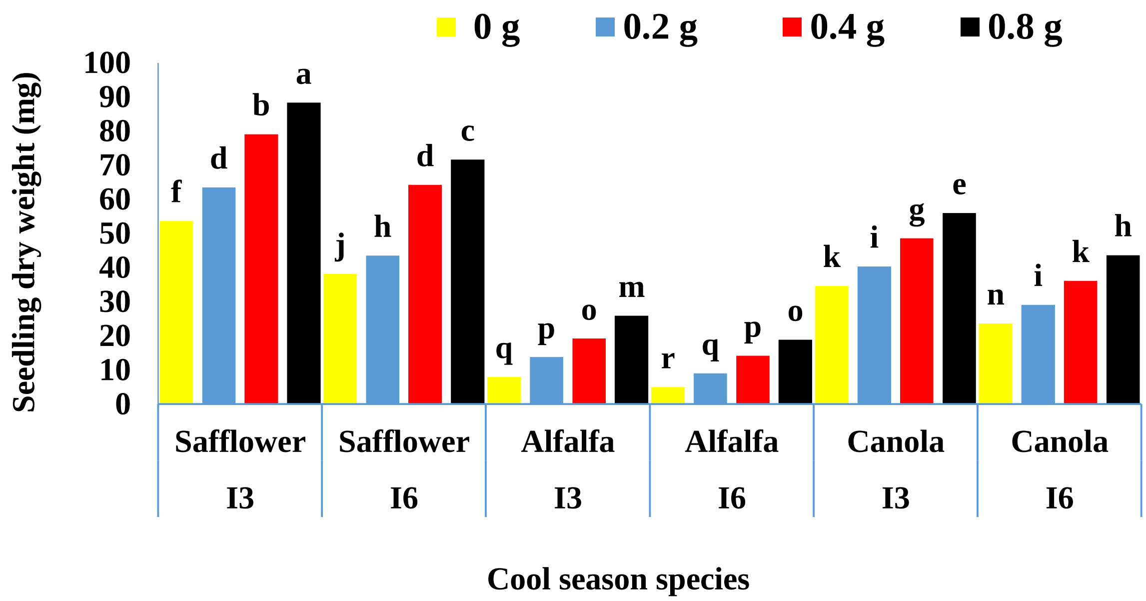


**Figure 2.** Effect of water-superabsorbent and drought stress on seedling dry weight in cool-season plants; I3 and I6 are irrigation intervals of 3 and 6 days, respectively. 0, 0.2, 0.4, and 0.8 g are water-superabsorbent polymer rates of 0, 0.2, 0.4, and 0.8 g per kg of soil, respectively. The means with the same letters were not statistically significant at the 0.05 probability level based on Duncan's multiple range test.

***Seedling dry weight*:** According to *the* analysis of variance, the three-way interaction of drought stress × water-superabsorbent × species was significant for the seedling dry weight (Table 3). In the irrigation intervals of 3 days, with the consumption of 0.8 grams of water-superabsorbent per kg of soil, seedling dry weight in safflower, alfalfa, and canola increased by 0.64, 2.32, and 0.61 times, respectively, compared to the control (without water-superabsorbent). Although in the irrigation interval of 6 days, the seedling dry weight decreased, the consumption of 0.8 grams of superabsorbent per kg of soil increased the seedling dry weight in safflower, alfalfa, and canola by 0.88, 2.78, and 0.85 times, respectively, compared to the control in each species. As shown, the increase in the percentage of seedling dry weight in alfalfa was higher than in safflower and canola in both irrigation intervals (Figure 2). In a research, hydrogel improved the biomass of *Picea abies* seedlings under drought conditions (Biehl *et al.* 2023), which concords with the results of the present study. The hydrogel forms a micro-water reserve that increases the soil moisture reserve, and when the soil moisture decreases, the moisture in the hydrogel is gradually released and becomes available to the plant roots (Qin *et al.* 2022). Hydrogel affects other soil properties such as soil aggregates and mineralization of soil organic matter; therefore, it preserves soil nutrients and increases soil fertility (Yang *et al*. 2022). Due to their high molecular weight and the ability to absorb and retain moisture, hydrogels are promising for dealing with drought stress (Guo *et al*. 2022).

***Emergence percentage*****:** Analysis of variance showed that the interaction of water deficit stress × water-superabsorbent was significant for the emergence percentage. The main effect of species on emergence percentage was also significant (Table 3). The irrigation interval of 3 days with the application of 0.8 grams of water-superabsorbent had the highest percentage of seedling emergence (100%). On the other hand, the irrigation interval of 6 days without the use of water superabsorbent had the lowest percentage of seedling emergence (34%). Thus, the use of water-superabsorbent had a favorable effect on the percentage of seedling emergence of the studied plants, and it is recommended to facilitate seedling emergence (Table 4). The probable cause of this phenomenon is that the water-superabsorbent creates good moisture conditions for germination and seedling emergence. The decrease in the percentage of emergence with increasing irrigation intervals may be due to a decrease in moisture content in the seedbed, and the probable cause of increasing the percentage of emergence by increasing the amount of water-superabsorbent is maintaining moisture in the seedbed. Kafi *et al*. (2005) and Huth *et al*. (2008) reported that with increasing levels of drought stress, the percentage of emergence in the studied plants decreased. One of the problems of the farm, especially in the soils of arid and semi-arid regions, is soil capping. Soil capping reduces the emergence of seedlings. There are different ways to break the soil capping. Among these is the strengthening of the soil aggregate, which is a permanent way to prevent soil capping. There are also temporary ways, such as irrigation, to deal with the soil capping. Keeping the soil wet can reduce the physical resistance of the soil against capping (Lal and Stewart 2012). The increase in the emergence of seedlings with superabsorbent can be attributed to the effect of this substance on more water absorption in the soil, the effect of hydrogel on the soil structure, and the reduction of the bulk density of the soil on the surface for the emergence of seedlings (Sheng *et al*. 2023).

***Emergence rate*:** The interaction of water deficit stress × water-superabsorbent and the species × water-superabsorbent was significant for the rate of emergence (Table 3). The use of water-superabsorbent polymer increased the seedling emergence rate in all three studied plants. The use of water-superabsorbent polymer at a rate of 0.8 grams per kilogram of soil increased the seedling emergence rate by 1.6, 1.4, and 1.2 times in safflower, alfalfa, and canola, respectively, compared to the control (without superabsorbent). It is evident that the increase in the rate of seedling emergence by increasing the amount of water-superabsorbent was higher in safflower than in alfalfa and canola. The irrigation interval of 3 days with the application of 0.8 grams of water-superabsorbent per kilogram of soil had the highest seedling emergence rate. The irrigation interval of 6 days without the use of water-superabsorbent, the irrigation interval of 6 days with the use of water superabsorbent at the rate of 0.2 g per kilogram of soil, and the irrigation interval of 3 days without the use of water-superabsorbent had the lowest seedling emergence rate (Table 4). Water-absorbing compounds can play a key role in the rate of emergence due to improved access to water (Kafi *et al*. 2005). Retention of moisture and nutrients for the plant (Rizwan *et al*. 2021), reduced water consumption (Verma *et al*. 2019), and low evaporation rate (Fang *et al*. 2018) due to the use of superabsorbent can help the better establishment of the plants in the soil.

## Conclusion

With increasing the water-superabsorbent application rate, seedling dry weight, seedling height, seedling emergence percentage, and seedling emergence rate increased in safflower, alfalfa, and canola. By increasing the irrigation interval, the mentioned traits were decreased, but the water-superabsorbent could alleviate the adverse effects of drought. Probably, drought causes partial closing of stomata, but the superabsorbent reduces the adverse effects of drought by saving water and increasing the access time to moisture. According to the results of this study, for the high seedling establishment of safflower, alfalfa, and canola, eight g per square meter of water-superabsorbent is proposed. The comparison of chemical water-superabsorbents with natural water-superabsorbents in terms of their effect on the seedling establishment is recommended for further studies.

## Conflict of Interest

The authors declare that they have no conflict of interest.


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## Authors contributions

AH conducted the experiment. HH designed the experiment and wrote the manuscript. HH, IN, and MK revised the manuscript.

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