# Effects of priming treatments on germination indices of soybean cultivars under osmotic stress

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This study aimed to investigate the effects of priming treatments on germination indices of soybean cultivars under osmotic stress in a completely randomized design with a factorial arrangement of treatments in a botany laboratory located in Kordestan Province, Sanandaj, Iran. Experimental treatments included three treatments of priming (control and gibberellin at a concentration of 0.04%), cultivar (Clark and Hobbit), and osmotic stress (control and -1.5MPa) in three replications. The standard germination test was performed according to the guidelines presented by the International Seed Testing Association (ISTA) and some germination indices, including germination percentage, germination rate, germination uniformity, and mean germination time up to 10% germination (D10), were calculated at the end of the experiment using Germin program. In addition, some growth indices and enzymatic activities were also evaluated in this study. Results of analysis of variance indicated that the triple interaction of A×B×C had significant effects on all germination indices and the lowest coefficient of variation (equal to 7.55) was obtained for germination rate while its highest value (equal to 17.22) was calculated for germination uniformity index. Concerning the effects of priming treatment, it was observed that the highest values for indices of germination percentage and germination rate (with averages of 48% and 0.12, respectively) were obtained under the application of gibberellin. In other words, gibberellin treatment led to increases equal to 15.58 and 90.44% for germination percentage and germination rate indices compared to the control treatment, respectively. In addition, increasing osmotic stress levels had a significant inverse relationship with germination indices so that the application of -1.5 MPa osmotic stress significantly Decreased the germination percentage and germination rate of both Clark and Hobbit cultivars. In general, it was concluded that the application of gibberellin mitigated adverse effects of osmotic stress of -1.5 MPa and resulted in increasing percentage and rate of germination under stressful conditions.

Keywords: Germination, Gibberellin, Osmotic stress, Soybean

## INTRODUCTION

Soybean (*Glycine max* L.), a self-pollinated diploid legume, is one of the most important oilseeds that makes up nearly 60% of the oilseed production in the world and its grains contain 40% protein, 20% oil, and high doses of B vitamins. The effects of climatic, environmental, and managerial factors on soybean, including moisture, soil temperature, air temperature, daylength, light intensity, soil pores, and soil conditions (soil fertility), are manifested through growth and developmental changes (Fataei, Monavari et al. 2010, Jia, Khayatnezhad et al. 2020, Arjaghi, Alasl et al. 2021, Bi, Chen et al. 2021, Chen, Khayatnezhad et al. 2021, Li, Mu et al. 2021). In general, soybeans are short-day (SD) and thermophilic plants that germinate at 8 to 10 ° C; however, the optimum temperature for its germination is around 30 ° C. In addition, it was reported that this plant is compatible with arid and semi-arid climate conditions, and its seeds mostly grow about 300 m elevation and daylength of 12 to 16 hours (Bi, Dan et al. 2021, Chen, Khayatnezhad et al. 2021, Cheng, Hong et al. 2021, Guo, She et al. 2021). Since soybean cultivars have relatively sensitive to day length, a 15-minute difference during the day may prevent flower growth and development in a unique cultivar (Tepperman and Dunsmuir 1990, Liu, Wang et al. 2021, Ma, Khayatnezhad et al. 2021, Peng, Khayatnezhad et al. 2021, Shi, Khayatnezhad et al. 2021). In addition to the above features, as a principle, early maturity groups of soybean cultivars need longer days for flowering, plant growth, and further development compared to late maturity groups (Jia, Khayatnezhad et al. 2020, Hou, Li et al. 2021, Huang, Wang et al. 2021).

Seed germination and emergence in seeds of many crops are the most sensitive stages in plants. In this regard, seed priming or priming technology, especially on soybean seeds, is one of the new methods of regulating seed germination in modern agriculture, in which seeds are first soaked in a solution for a definite time and dried

before emerging the radicle(Gholamin and Khayatnezhad 2020, Karasakal, Khayatnezhad et al. 2020, Ma, Ji et al. 2021, Zhu, Liu et al. 2021, Wang, Ma et al. 2022). Then, seed re-germination begins in the field at an appropriate time (as soon as conditions allow) using irrigation. Subsequently, the metabolic and physiological functions of the seeds continue, and plants begin to grow faster than expected conditions(Si, Gao et al. 2020, Garcia, Arif et al. 2021, Wang, Shang et al. 2021, Wang, Ye et al. 2021, Yin, Khayatnezhad et al. 2021).

On the other hand, since Iran is located in arid and semi-arid regions, water scarcity is one of the most important agricultural problems, and drought stress is a serious threat for global food security and plant production. According to the above definition of seed priming, the primary purpose of priming is to facilitate germination and promote the physiological and metabolic functions of seeds under particular environmental conditions, which leads to improved germination percentage and germination rate indices under challenging environments(Fataei, Varamesh et al. 2018, Gholamin and Khayatnezhad 2020, Sun and Khayatnezhad 2021). Also, priming minimizes the induced dormancy periods for various seeds by temperature and increases the temperature range required for seed germination(Abdi 2021, Alizadeh 2021, Karasakal 2021, Mohammadzadeh 2021, Radmanesh 2021). Overall, the term priming refers to the soaking of seeds in osmotic solutions with more negative water potential and ventilated, in which environmental conditions (e.g., temperature, light, and others) have significant effects on oxygen availability, the passage of time, seed drying, and control the seed-borne microbial contaminations during the dehydration process (Si, Gao et al. 2020, Guo, She et al. 2021, Khayatnezhad and Gholamin 2021, Li, Mu et al. 2021). In the meantime, gibberellic acid is a plant hormone and stimulant affecting the seed germination and dormancy in various plant species, which is employed as a priming solution for seeds. For more than two decades, seed priming has been applied as a standard method in many plants to alleviate the depressive effects of drought(Gholamin and Khayatnezhad 2020, Karasakal, Khayatnezhad et al. 2020). However, studies on the optimal reactions of primed and non-primed seeds are still under investigation, and seed priming continues until final evolution as a helpful technology. Accordingly, additional and further information becomes gradually available about primed seeds (Xiao, Yu et al. 2004, Zhao, Wang et al. 2021, Zheng, Zhao et al. 2021, Zhu, Saadati et al. 2021).

## MATERIALS AND METHODS
This study aimed to investigate the effects of priming treatment on germination indices of soybean cultivars under osmotic stress. Therefore, an experiment was performed as a three-way factorial arrangement based on the completely randomized design in the fall season, 2020, in a botanical laboratory. Experimental treatments included priming as factor A (a1: control and a2: gibberellin at a concentration of 0.04%), osmotic stress as factor B (b1: control and b2: -1.5MPa), and cultivar as factor C (c1: Clark and c2: Hobbit) in three replications. The standard germination tests were performed according to the ISTA Rules with slight modifications. Seed priming experiments (e.g., maximum germination, germination rate, and germination uniformity) were conducted as Petri experiments ((Hemmati, Fataei et al. 2019, Gholamin and Khayatnezhad 2020). Accordingly, three replicates of 25 seeds (5 series of 25 healthy seeds) were first counted to determine rate, percentage, and uniformity of germination. Next, seeds were disinfected with the carboxin-thiram fungicide to maintain and improve seed quality before planting in the culture medium. The seeds were then placed in Petri dishes (between two Whatman filters) and transferred to a growth chamber at 20±1 ° C. The number of germinated seeds scored three times per day for the time necessary to achieve the final number of germinated seeds. Hence, seeds were considered as germinated when their radicle length was more than or equal to 2 mm, and counting operations continued until the number of germinated seeds for each sample remained constant for three consecutive days. It should be noted that the Germin program, which calculates the indices of D10 (time up to 10% of maximum germination), D50 (time up to 50% of maximum germination), and D90 (time up to 90% of maximum germination), was employed for calculating traits of final germination percentage and germination rate (Mohammadi and Fataei 2019, Gholamin and Khayatnezhad 2021). This program calculates the above parameters for each replicate/seed treatment by interpolation from the progress of germination (%) versus the time curve. The germination rate, also called R50, was calculated in hours by the following equation (Soltani and Galeshi 2002).

Equation (1)
$$R50 = \frac{1}{D50}$$

Germination uniformity (GU) refers to the time required for 90% maximum germination subtracted by the time required for 10% maximum germination and is calculated by the following equation (Equation 2). In general, a lower value of this number indicates more uniform germination (simultaneous germination) of seeds.

Equation (2)
$$GU = D90 - D10$$

## Statistical analysis
The obtained data were first normalized for different studied traits and then analyzed using SPSS 24 and MSTAT-C 21 statistical software. Also, the LSD test was used to compare means at p<0.05, and charts were drawn using Excel software.

## RESULTS AND DISCUSSION
Drought stress is one of the most important factors

limiting growth, development, and crop production in soybean and is considered a major challenging factor in many countries facing water scarcity (Nasehi and Fataei 2012, Yin, Khayatnezhad et al. 2021). Depending on the type of the plant and stress intensity, different methods have been used by numerous researchers and farmers to overcome water stress (Tao, Cui et al. 2021, Zhu, Saadati et al. 2021). Results of analysis of variance (Table 1) showed that factor A (priming), factor B (osmotic stress), and interactions of A × B, A × C, and A × B × C had significant effects on all germination indices. In addition, factor C (cultivar) and the interaction of B × C also caused significant differences in the obtained values of germination percentage, germination rate, and time up to 10% of maximum germination; however, both factor C and the interaction of B × C had no significant effects on germination uniformity. According to the data, the lowest coefficient of variation was (equal to 7.55) obtained for germination rate, while the highest value (with an average of 17.22) was observed for germination uniformity. In general, high values of coefficient of variation for GU and D10 indicate high effects of the environment on the above traits

In confirmation of the adverse effects of stressful conditions on germination indices, Yagmur and Kaydan(2008) revealed that osmotic stress reduced germination traits of triticale seeds. The negative impacts of osmotic stress on the initial growth of seeds of different plants were also investigated and confirmed by other researchers (Omrani and Fataei 2018, Khayatnezhad and Gholamin 2020, Li, Mu et al. 2021, Xu, Ouyang et al. 2021). Xu et al. (2021) reported that drought stress and gibberellin priming significantly affected germination percentage, seedling length, dry weight of the treated seedlings, and seedling length and weight indices at p <0.01. In addition, these traits were significantly affected by the interaction of gibberellin × drought stress (p <0.01). Results presented by Khaliliaqdam and Mir-Mahmoodi (2013)also confirmed the significant effects of priming treatments on all germination indices of soybean seeds. In another study, Khalili et al. (2014) also reported that GP, R50, D10, D50, and D90 were significantly affected by temperature, water potential, and their interaction at p <0.01.

**Germination percentage**

Seed germination depends on numerous environmental factors. In the meantime, water (and its availability) is one of the most influential factors in initiating seed germination and the physical and physiological processes of seed germination. Findings of some studies also indicated an increase in growth inhibitors, such as abscisic acid, and a decrease in growth-promoting hormones, e.g., auxins, gibberellins, and cytokinins, in plants under water scarcity conditions (Rajaei, Khalili-Arjaghi et al. 2020, Alizadeh 2021, Karasakal 2021, Mohammadzadeh 2021, Radmanesh 2021, Zhang,

Khayatnezhad et al. 2021). In the present study, the highest germination percentage (with an average of 90%) was recorded for the absence of gibberellin × absence of osmotic stress × Hobbit cultivar interaction, which placed in class A along with the absence of gibberellin × absence of osmotic stress × Clark cultivar interaction. In contrast, the germination percentage of seeds under treatments containing osmotic stress of -1.5 MPa was less than 10%. Results also showed that the germination percentage of seeds of Clark and Hobbit cultivars primed with gibberellin under -1.5 MPa conditions significantly increased compared to normal conditions. In other words, applying gibberellin reduced the adverse effects of osmotic stress (-1.5 MPa) and improved germination percentage (Fig. 1).
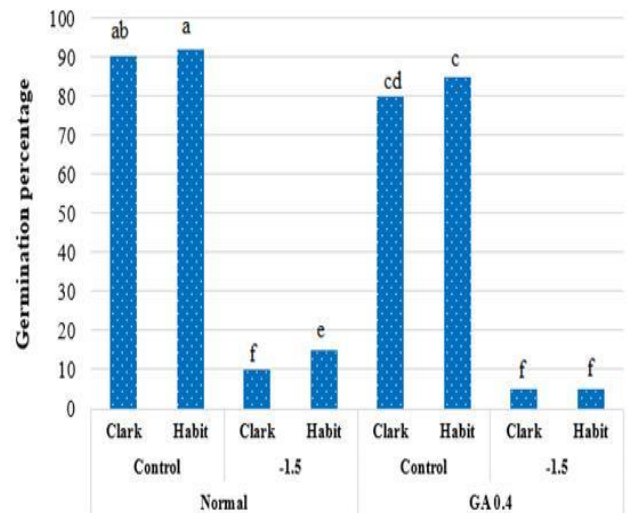


**Figure1: Effects of tripartite interaction of priming ×osmotic stress ×cultivar (A×B×C) on germination percentage**

Means sharing the same superscript are not significantly different from each other at p<0.05 of the LSD test

Ghassemi-Golezani et al. (2008) reported an increase in the germination percentage of lentil seeds under priming with distilled water. They also stated that different responses of various genotypes to drought stress might depend on several factors, e.g., seed size, seed cover, and other characteristics. Decreasing water entrance into the seed under increasing drought stress can reduce hydraulic conductivity and thus decline the rate of physiological and metabolic processes involved in seed germination (Varamesh, Hosseini et al. 2014, Khayatnezhad and Gholamin 2020). Ghaffari et al. (2012) reported that although increasing stress levels resulted in a significant reduction in germination percentage, gibberellin treatment significantly increased seed germination percentage.

**Table 1: Analysis of variance (mean squares) of the studied treatments on seed germination indices**

| Sources of variations | df | Germination percentage ($G_{max}$) | Germination rate (R50) | Germination uniformity (GU) | time up to 10% of maximum germination (D10) |
|---|---|---|---|---|---|
| Rep | 2 | 50.5 [*] | 0.0000004 [ns] | 111.2 [ns] | 34.14 [ns] |
| Priming (Factor A) | 1 | 82.08 [**] | 0.00003 [**] | 805.52 [**] | 420.22 [**] |
| Osmotic stress (Factor B) | 1 | 3842.44 [**] | 0.0032 [**] | 1132.8 [**] | 1128.4 [**] |
| A×B interaction | 1 | 1546.01 [**] | 0.00005 [**] | 1952.22 [**] | 381.3 [**] |
| Cultivar (Factor C) | 1 | 1208 [**] | 0.0001 [**] | 8.85 [ns] | 2018.5 [**] |
| A×C interaction | 1 | 752.7 [**] | 0.00003 [**] | 988.5 [**] | 382.3 [**] |
| B×C interaction | 1 | 985.2 [**] | 0.00003 [**] | 138.3 [ns] | 2152.1 [**] |
| A×B×C interaction | 1 | 914.4 [**] | 0.000011 [**] | 1528.22 [**] | 346.54 [**] |
| E (Error) | 51 | 19.521 | 0.0000003 | 68.32 | 25.22 |
| Coefficient of variation (%) | | 8.88 | 7.55 | 17.22 | 16.34 |

ns: non-significant; * and **: significant at p<0.05 and p<0.01, respectively

## Germination rate

Regulation and completion of metabolic stages involved in seed germination are the main reasons for increasing the germination rate of plant seeds under different priming treatments. In general, since non-primed seeds spend time performing phases I and II (rapid water imbibition by seed and reactivation of metabolism, respectively) longer, primed seeds are one step ahead of non-primed seeds in terms of germination and emergence stages (Garcia et al., 2021). Therefore, the cultivation of primed seeds, especially in unfavorable environmental conditions, leads to increased germination rate and germination percentage (Ren and Khayatnezhad 2021). Here, the highest germination rate was assigned to interactions of the absence of gibberellin×the absence of osmotic stress×Clark cultivar, the absence of gibberellin×the absence of osmotic stress×Hobbit cultivar, gibberellin treatment×the absence of osmotic stress×Clark cultivar, and gibberellin treatment×the absence of osmotic stress×Hobbit cultivar(Khayatnezhad and Gholamin 2021). Hence, all of the mentioned interactions were marked with the letter A and placed in the same group. According to the data, the application of gibberellin moderated adverse effects of drought stress-induced osmotic stress and led to increased germination rate in primed seeds of both Hobbit and Clark cultivars (Fig. 2). Decreased germination rate under stressful environmental conditions can also be directly correlated with reduced water absorption by seeds. As a whole, Hosseini and Rezvani Moghadam (2006) stated that seeds without priming solutions have low germination-related metabolic activities due to slow water uptake. Accordingly, the time required for radicle emergence and seed germination rate indices can be increased and decreased, respectively.
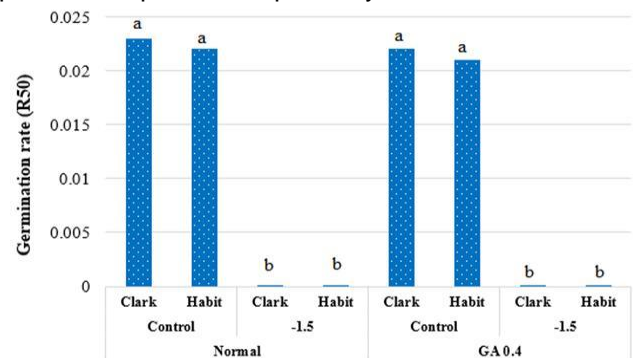


**Figure 2: Effects of tripartite interaction of priming × osmotics tress×cultivar (A×B×C) on germination rate**
Means sharing the same superscript are not significantly different from each other at p<0.05 of the LSD test

## Germination uniformity and time up to 10% of maximum germination (D10)

Germination uniformity was calculated based on the time required for 90% germination subtracted by the time required for 10% germination, namely D90-D10, in which scores with a lower value indicate a shorter time interval between 10% and 90% of seed germination and more favorable germination uniformity (Khayatnezhad and Nasehi 2021, Wang, Shang et al. 2021). Some researchers also stated that the lower absolute value for the obtained values indicated more uniformity for the germinated seeds (Sun, Lin et al. 2021, Li, Khayatnezhad et al. 2022, Wang, Khayatnezhad et al. 2022, Zhang, Khayatnezhad et al. 2022). Accordingly, since these seeds absorb water more rapidly under the same conditions, their germination rate and D10 occur higher and lower values, respectively. Based on the evidence, Rafiei(2001) stated that higher osmotic potential (less negative ψπ ) and less water absorption under stressful environmental conditions could lead to reducing germination rate, decreasing germination uniformity, and increasing time up to 10% of maximum germination; accordingly, seeds reached to final germination percentage in the longer growing periods. In this regard, our findings demonstrated that the lowest GU value

(namely the highest germination uniformity) was attributed to the interaction (combined treatment) of gibberellin × osmotic stress × Clark cultivar (Fig. 3).
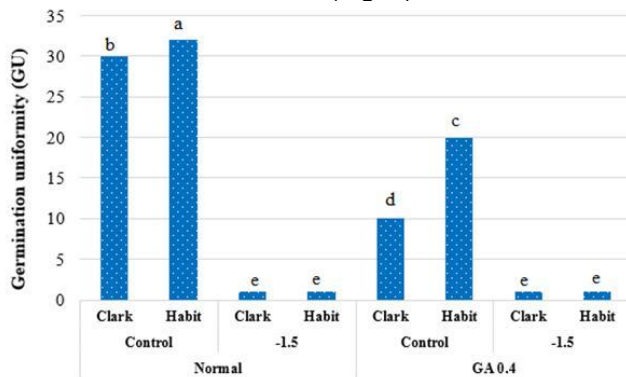


**Figure 3: Effects of tripartite interaction of priming× osmotic stress ×cultivar (A×B×C) on germination uniformity**

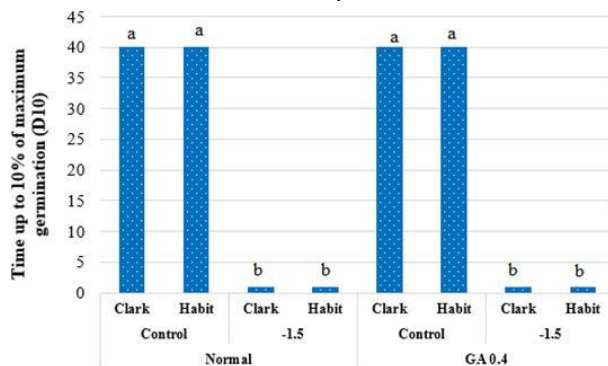Means sharing the same superscript are not significantly different from each other at p<0.05 of the LSD test



**Figure 4: Effects of tripartite interaction of priming× osmotic stress× cultivar (A×B×C) on time up to 10% of maximum germination**

Means sharing the same superscript are not significantly different from each other at p<0.05 of the LSD test

## CONCLUSION

In general, our findings showed that the highest germination percentage and germination rate (with average values of 48% and 0.12, respectively) were obtained for seeds primed with gibberellin and had increases of 18.58 and 90.44% for the above traits compared to the control treatment. On the other hand, osmotic stress had a significant inverse relationship with percentage and rate of germination indices in both studied cultivars. In other words, the application of -1.5 MPa osmotic stress caused notable reductions in germination percentage and germination rate indices compared to the normal conditions (absence of osmotic stress).

## CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

## AUTHOR CONTRIBUTIONS

Masoud Radmanesh conducted, planned, Analyzed the data, wrote manuscript and interpreted the results and involved in manuscript preparation. All authors read and approved the final version.

## REFERENCES

Abdi, M. M. (2021). "Evaluation of spring bread wheat lines/varieties in international observation nurseries and yield trials in moderat region of Iran." Bioscience Research 18(3): 2127-2134.

Alizadeh, M. (2021). "Enhanced Imazethapyr Activity on Jimsonweed using natural Additives." Bioscience Research 18(4): 3080-3086.

Alizadeh, M. (2021). "Protein profile and seeds storage proteins changes in wheat genotypes under control and drought stress conditions." Bioscience Research 18(3): 2164-2169.

Arjaghi, S. K., M. K. Alasl, N. Sajjadi, E. Fataei and G. E. Rajaei (2021). "Green Synthesis of Iron Oxide Nanoparticles by RS Lichen Extract and its Application in Removing Heavy Metals of Lead and Cadmium." Biological trace element research 199(2).

Bi, D., D. Chen, M. Khayatnezhad, Z. S. Hashjin, Z. Li and Y. Ma (2021). "molecular identification and genetic diversity in hypericum l.: a high value medicinal plant using rapd markers markers." Genetika-Belgrade 53(1): 393-405.

Bi, D., C. Dan, M. Khayatnezhad, Z. sayyah hashjin, z. li and y. ma (2021). "molecular identification and genetic diversity in hypericum l.: a high value medicinal plant using rapd markers markers." Genetika 53(1): 393-405.

Chen, W., M. Khayatnezhad and N. Sarhadi (2021). "Gene flow and population structure in Allochrusa (caryophylloideae, caryophyllaceae) with the use of molecular markers." Genetika 53(2): 799-812.

Chen, W., M. Khayatnezhad and N. Sarhadi (2021). "protok gena i struktura populacije kod allochrusa (caryophylloideae, caryophyllaceae) pomocu molekularnih MARKERA." Genetika-Belgrade 53(2): 799-812.

Cheng, X., X. Hong, M. Khayatnezhad and F. Ullah (2021). "Genetic diversity and comparative study of genomic DNA extraction protocols in Tamarix L. species." Caryologia 74(2): 131-139.

Fataei, E., S. Monavari, A. Hasani, A. Karbasi and S. Mirbagheri (2010). "Heavy metal and agricultural toxics monitoring in Garasou river in Iran for water quality assessment." Asian Journal of Chemistry 22(4): 2991-3000.

Fataei, E., S. Varamesh and S. Safavian (2018). "Effects of afforestation on carbon stocks in fandoghloo forest area." Pakistan Journal of Agricultural Sciences 55(3): 555–562.

Garcia, D., S. Arif, Y. Zhao, S. Zhao, L. C. Ming and D. Huang (2021). "Seed Priming Technology as a Key Strategy to Increase Crop Plant Production under Adverse Environmental Conditions."

GHASSEMI-GOLEZANI, K., A. Aliloo, M. Valizadeh and M. MOGHADDAM (2008). "Effects of hydro and osmo-priming on seed germination and field emergence of lentil (Lens culinaris Medik.)." Notulae Botanicae Horti Agrobotanici Cluj-Napoca 36(1): 29-33.

Gholamin, R. and M. Khayatnezhad (2020). "Assessment of the Correlation between Chlorophyll Content and Drought Resistance in Corn Cultivars (Zea Mays)." Helix 10(5): 93-97.

Gholamin, R. and M. Khayatnezhad (2020). "The effect of dry season stretch on Chlorophyll Content and RWC of Wheat Genotypes (Triticum Durum L.)." Bioscience Biotechnology Research Communications 13(4): 1829-1833.

Gholamin, R. and M. Khayatnezhad (2020). "Study of Bread Wheat Genotype Physiological and Biochemical Responses to Drought Stress." Helix 10(5): 87-92.

Gholamin, R. and M. Khayatnezhad (2020). "The Study of Path Analysis for Durum Wheat (Triticum durum Desf.) Yield Components." Bioscience Biotechnology Research Communications 13(4): 2139-2144.

Gholamin, R. and M. Khayatnezhad (2021). "Impacts of PEG-6000-induced Drought Stress on Chlorophyll Content, Relative Water Content (RWC), and RNA Content of Peanut (Arachis hypogaea L.) Roots and Leaves." Bioscience Research 18(1): 393-402.

Guo, L.-N., C. She, D.-B. Kong, S.-L. Yan, Y.-P. Xu, M. Khayatnezhad and F. Gholinia (2021). "Prediction of the effects of climate change on hydroelectric generation, electricity demand, and emissions of greenhouse gases under climatic scenarios and optimized ANN model." Energy Reports 7: 5431-5445.

Hemmati, S., E. Fataei and A. A. Imani (2019). "Effects of Source Separation Education on Solid Waste Reduction in Developing Countries (A Case Study: Ardabil, Iran)." The Journal of Solid Waste Technology and Management 45(3): 267-272.

HOSSEINI, H. and M. P. REZVANI (2006). "Effect of water and salinity stress in seed germination on Isabgol (Plantago ovata)."

Hou, R., S. Li, M. Wu, G. Ren, W. Gao, M. Khayatnezhad and F. gholinia (2021). "Assessing of impact climate parameters on the gap between hydropower supply and electricity demand by RCPs scenarios and optimized ANN by the improved Pathfinder (IPF) algorithm." Energy 237: 121621.

Hu, W., R. Kaminski, F. Yang, Y. Zhang, L. Cosentino, F. Li, B. Luo, D. Alvarez-Carbonell, Y. Garcia-Mesa and J. Karn (2014). "RNA-directed gene editing specifically eradicates latent and prevents new HIV-1 infection." Proceedings of the National Academy of Sciences 111(31): 11461-11466.

Huang, D., J. Wang and M. Khayatnezhad (2021). "Estimation of Actual Evapotranspiration Using Soil Moisture Balance and Remote Sensing." Iranian Journal of Science and Technology, Transactions of Civil Engineering: 1-8.

Jia, Y., M. Khayatnezhad and S. Mehri (2020). "POPULATION DIFFERENTIATION AND GENE FLOW IN Erodium cicutarium: A POTENTIAL MEDICINAL PLANT." Genetika-Belgrade 52(3): 1127-1144.

Jia, Y., M. Khayatnezhad and S. Mehri (2020). "Population differentiation and gene flow in Rrodium cicutarium: A potential medicinal plant." Genetika 52(3): 1127-1144.

Karasakal, A. (2021). "Composted organic manure replacement probability using chemical fertilizer in organic Safflower farming." Bioscience Research 18(4): 3115-3124.

Karasakal, A. (2021). "Production of Wheat Seed Through Various Plantation Practices in Maternal Environment." Bioscience Biotechnology Research Communications 14(2): 549-552.

Karasakal, A., M. Khayatnezhad and R. Gholamin (2020). "The Durum Wheat Gene Sequence Response Assessment of Triticum durum for Dehydration Situations Utilizing Different Indicators of Water Deficiency." Bioscience Biotechnology Research Communications 13(4): 2050-2057.

Karasakal, A., M. Khayatnezhad and R. Gholamin (2020). "The Effect of Saline, Drought, and Presowing Salt Stress on Nitrate Reductase Activity in Varieties of Eleusine coracana (Gaertn)." Bioscience Biotechnology Research Communications 13(4): 2087-2091.

Khayatnezhad, M. and R. Gholamin (2020). "A Modern Equation for Determining the Dry-spell Resistance of Crops to Identify Suitable Seeds for the Breeding Program Using Modified Stress Tolerance Index (MSTI)." Bioscience Biotechnology Research Communications 13(4): 2114-2117.

Khayatnezhad, M. and R. Gholamin (2020). "Study of Durum Wheat Genotypes' Response to Drought

Stress Conditions." Helix 10(5): 98-103.

Khayatnezhad, M. and R. Gholamin (2021). "The Effect of Drought Stress on the Superoxide Dismutase and Chlorophyll Content in Durum Wheat Genotypes." Advancements in Life Sciences 8(2): 119-123.

Khayatnezhad, M. and R. Gholamin (2021). "Impacts of Drought Stress on Corn Cultivars (Zea mays L.) At the Germination Stage." Bioscience Research 18(1): 409-414.

Khayatnezhad, M. and F. Nasehi (2021). "Industrial Pesticides and a Methods Assessment for the Reduction of Associated Risks: A Review." Advancements in Life Sciences 8(2): 202-210.

Li, A., X. Mu, X. Zhao, J. Xu, M. Khayatnezhad and R. Lalehzari (2021). "Developing the non-dimensional framework for water distribution formulation to evaluate sprinkler irrigation." Irrigation and Drainage 70(4): 659-667.

Li, A., X. Mu, X. Zhao, J. Xu, M. Khayatnezhad and R. Lalehzari (2021). "Developing the non-dimensional framework for water distribution formulation to evaluate sprinkler irrigation." Irrigation and Drainage.

Li, W., M. Khayatnezhad and A. Davarpanah (2022). "Statistical Analysis of Treated Flow-Back Water Measurements: An Industrial Insight for a Shale Reservoir." Geofluids 2022.

Liu, S., Y. Wang, Y. Song, M. Khayatnezhad and A. A. Minaeifar (2021). "Genetic variations and interspecific relationships in Salvia (Lamiaceae) using SCoT molecular markers." Caryologia 74(3): 77-89.

Ma, A., J. Ji and M. Khayatnezhad (2021). "Risk-constrained non-probabilistic scheduling of coordinated power-to-gas conversion facility and natural gas storage in power and gas based energy systems." Sustainable Energy Grids & Networks 26.

Ma, S., M. Khayatnezhad and A. A. Minaeifar (2021). "Genetic diversity and relationships among Hypericum L. species by ISSR Markers: A high value medicinal plant from Northern of Iran." Caryologia 74(1): 97-107.

Mir-Mahmoodi, T., N. Khaliliaqdam, A. Pirmani, S. Yazdan-Sta and S. Sharafi (2013). "Effects of hydro priming on laboratory indexes and field performance of sunflower seeds." International Journal of AgriScience 3(12): 904-911.

Mohammadi, M. and E. Fataei (2019). "Comparative life cycle assessment of municipal wastewater treatment systems: lagoon and activated sludge." Caspian Journal of Environmental Sciences 17(4): 327-336.

Mohammadzadeh, S. (2021). "The impact of trellising strategies on the production and quality of determinate tomato types." Bioscience Research 18(4): 3264-3271.

Mohammadzadeh, S. (2021). "The presence of Nickel Sulphate in soil influences the synthesis of flavonoids and phenols in garlic (Allium sativum L.), changing its

allelopathic potential." Bioscience Research 18(4): 3125-3131.

Nasehi, F. and E. Fataei (2012). "Measurement of residue levels of agro-chemicals in water and sediment of Aras River." Journal of Food, Agriculture & Environment 10(1): 933-936.

Omrani, M. and E. Fataei (2018). "Synthesizing Colloidal Zinc Oxide Nanoparticles for Effective Disinfection; Impact on the Inhibitory Growth of Pseudomonas aeruginosa on the Surface of an Infectious Unit." Polish Journal of Environmental Studies 27(4).

Peng, X., M. Khayatnezhad and L. J. Ghezeljehmeidan (2021). "RAPD PROFILING IN DETECTING GENETIC VARIATION IN Stellaria L. (Caryophyllaceae)." Genetika-Belgrade 53(1): 349-362.

Radmanesh, M. (2021). "The Combined and Isolated Effect of Spinosad and Nuclear Polyhedrosis Virus on the Mediterranean Brocade Spodoptera littoralis in laboratory Conditions." Bioscience Biotechnology Research Communications 14(2): 692-696.

Radmanesh, M. (2021). "Impacts of salinity, Pseudomonas and salicylic acid on seed bean physiological properties and yield (Phaseolus vulgaris)." Bioscience Research 18(4): 3023-3030.

Rafiei, S.-R., H. A. Toliyat, R. Ghazi and T. Gopalarathnam (2001). "An optimal and flexible control strategy for active filtering and power factor correction under non-sinusoidal line voltages." IEEE Transactions on Power Delivery 16(2): 297-305.

Rajaei, G. E., S. Khalili-Arjaghi, E. Fataei, N. Sajjadi and M. Kashefi-Alasl (2020). "Fabrication and characterization of polymer-based nanocomposite membrane modified by magnetite nanoparticles for $Cd^{2+}$ and $Pb^{2+}$ removal from aqueous solutions." Comptes Rendus. Chimie 23(9-10): 563-574.

Ren, J. and M. Khayatnezhad (2021). "Evaluating the stormwater management model to improve urban water allocation system in drought conditions." Water Supply.

Shi, B., M. Khayatnezhad and A. Shakoor (2021). "The interacting effects of genetic variation in Geranium subg. Geranium (Geraniaceae) using scot molecular markers." Caryologia 74(3): 141-150.

Si, X., L. Gao, Y. Song, M. Khayatnezhad and A. A. Minaeifar (2020). "Understanding population differentiation using geographical, morphological and genetic characterization in Erodium cicunium." Indian Journal of Genetics and Plant Breeding 80(4): 459-+.

Si, X., L. Gao, Y. Song, M. Khayatnezhad and A. A. Minaeifar (2020). "Understanding population differentiation using geographical, morphological and genetic characterization in Erodium cicunium." Indian J. Genet 80(4): 459-467.

Soltani, A. and S. Galeshi (2002). "Importance of rapid canopy closure for wheat production in a temperate

sub-humid environment: experimentation and simulation." Field Crops Research 77(1): 17-30.

Sun, Q., D. Lin, M. Khayatnezhad and M. Taghavi (2021). "Investigation of phosphoric acid fuel cell, linear Fresnel solar reflector and Organic Rankine Cycle polygeneration energy system in different climatic conditions." Process Safety and Environmental Protection 147: 993-1008.

Sun, X. and M. Khayatnezhad (2021). "Fuzzy-probabilistic modeling the flood characteristics using bivariate frequency analysis and alpha-cut decomposition." Water Supply 21(8): 4391-4403.

Tao, Z., Z. Cui, J. Yu and M. Khayatnezhad (2021). "Finite Difference Modelings of Groundwater Flow for Constructing Artificial Recharge Structures." Iranian Journal of Science and Technology, Transactions of Civil Engineering.

Tepperman, J. M. and P. Dunsmuir (1990). "Transformed plants with elevated levels of chloroplastic SOD are not more resistant to superoxide toxicity." Plant molecular biology 14(4): 501-511.

Varamesh, S., S. M. Hosseini, F. K. Behjou and E. Fataei (2014). "The impact of land afforestation on carbon stocks surrounding Tehran, Iran." Journal of forestry research 25(1): 135-141.

Wang, C., Y. Shang and M. Khayatnezhad (2021). "Fuzzy Stress-based Modeling for Probabilistic Irrigation Planning Using Copula-NSPSO." Water Resources Management 35(14): 4943-4959.

Wang, C., Y. Shang and M. Khayatnezhad (2021). "Fuzzy Stress-based Modeling for Probabilistic Irrigation Planning Using Copula-NSPSO." Water Resources Management.

Wang, H., M. Khayatnezhad and N. Youssefi (2022). "Using an optimized soil and water assessment tool by deep belief networks to evaluate the impact of land use and climate change on water resources." Concurrency and Computation-Practice & Experience 34(10).

Wang, J., Q. Ye, C. Wang, T. Zhang, X. Shi, M. Khayatnezhad and A. Shakoor (2021). "Palynological analysis of genus Geranium (Geraniaceae) and its systematic implications using scanning electron microscopy." Caryologia 74(3): 31-43.

Wang, S., J. Ma, W. Li, M. Khayatnezhad and B. D. Rouyendegh (2022). "An optimal configuration for hybrid SOFC, gas turbine, and Proton Exchange Membrane Electrolyzer using a developed Aquila Optimizer." International Journal of Hydrogen Energy 47(14): 8943-8955.

Xiao, B., Z. Yu, W. Huang, J. Song and P. a. Peng (2004). "Black carbon and kerogen in soils and sediments. 2. Their roles in equilibrium sorption of less-polar organic pollutants." Environmental science & technology 38(22): 5842-5852.

Xu, Y.-P., P. Ouyang, S.-M. Xing, L.-Y. Qi, M. Khayatnezhad and H. Jafari (2021). "Optimal

structure design of a PV/FC HRES using amended Water Strider Algorithm." Energy Reports 7: 2057-2067.

Yagmur, M. and D. Kaydan (2008). "Alleviation of osmotic stress of water and salt in germination and seedling growth of triticale with seed priming treatments." African Journal of Biotechnology 7(13).

Yin, J., M. Khayatnezhad and A. Shakoor (2021). "evaluation of genetic diversity in geranium (geraniaceae) using rapd marker." Genetika 53(1): 363-378.

Yin, J., M. khayatnezhad and a. shakoor (2021). "evaluation of genetic diversity in geranium (geraniaceae) using rapd marker." Genetika-Belgrade 53(1): 363-378.

Zhang, H., M. Khayatnezhad and A. Davarpanah (2021). "Experimental investigation on the application of carbon dioxide adsorption for a shale reservoir." Energy Science & Engineering n/a(n/a).

Zhang, J., M. Khayatnezhad and N. Ghadimi (2022). "Optimal model evaluation of the proton-exchange membrane fuel cells based on deep learning and modified African Vulture Optimization Algorithm." Energy Sources Part a-Recovery Utilization and Environmental Effects 44(1): 287-305.

Zhao, Y., H. Wang, W. Liang, M. Khayatnezhad and Faisal (2021). "GENETIC DIVERSITY AND RELATIONSHIPS AMONG SALVIA SPECIES BY ISSR MARKERS." Genetika-Belgrade 53(2): 559-574.

Zheng, R., S. Zhao, M. Khayatnezhad and S. A. Shah (2021). "Comparative study and genetic diversity in Salvia ( Lamiaceae) using RAPD Molecular Markers." Caryologia 74(2): 45-56.

Zhu, K., L. Liu, S. Li, B. Li, M. Khayatnezhad and A. Shakoor (2021). "Morphological method and molecular marker determine genetic diversity and population structure in Allochrusa." Caryologia 74(2): 121-130.

Zhu, P., H. Saadati and M. Khayatnezhad (2021). "Application of probability decision system and particle swarm optimization for improving soil moisture content." Water Supply 21(8): 4145-4152.
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