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Impact of Seed Priming Treatments to Enhance Germination of Black Mustard Against Dormancy

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Abstract
Black mustard (Brassica nigra L. Brassicaceae) represents an important source of raw materials for many agro-industry branches in Turkey and elsewhere in the world. Black mustard is a highly significant plant for its aromatic, medicinal, and therapeutic uses, as well as its potential as an alternative energy plant. In our country, cultivar development studies are carried out on wild genotypes of this species. One of the major challenges to black mustard growth and yield is its homogeneous, simultaneous, and fast emergence. Presoaking seeds in water (hydroprimed) and polyethylene glycol (PEG) (osmoprimed), has been demonstrated to enhance the germination of seeds of different species. The seeds of pure line black mustard originated in the Ankara, Turkey, and were used in this study. The purpose of the study was to measure the effects of durations (12, 24, 36, and 48 h); unprimed, hydroprimed, and five osmoprimed doses (-0.1, -0.2, -0.4, 0.6, and -0.8 MPa of PEG) treatments on seed germi-nation and seedling establishment characteristics of black mustard for 14 days. The present findings demonstrate that priming durations and treatments of black mustard seeds significantly affected final germination percentage, mean germination time, root and seedling length, and seedling fresh and dry weight among different treatments compared to the control. This positive effect on germination especially shortened the mean germination time. In terms of the properties studied, the optimal priming time is 12 and 24 h, for hyropriming and osmopriming doses (-0.1, -0.2, and -0.4 Mpa of PEG). The study indicated that the implemented priming treatments can be useful in improving the capability of black mustard on germination treatments.

Key words
Hydropriming; Osmopriming; Priming duration; Germination; *Brassica nigra*.

Introduction
Black mustard (*Brassica nigra* L. *Brassicaceae*) is an annual growth habit plant, is widely cultivated for its blackish brown-red seeds that are slightly more pungent than the other mustard seeds, such as white or brown mustard (Palle-Reisch et al., 2013; Kayacetin, 2020; Lietzow, 2021). It is important for its aromatic and medicinal uses (Darwesh, 2017; Nisar et al., 2018; Asaduzzaman et al., 2021; Mayekar et al., 2021) as well as its potential as an alternative energy plant (Kinay and Kayacetin, 2023).

In the entire life cycle of the plant, seed germination is the initial step for growth and development, which result in the emergence of a radicle to form a primary root (Kayacetin et al., 2018). Quantitative parameters like final germination percentage, mean germination time, root and seedling length, seedling fresh and dry weight, and synchronization of the whole germination process are thought to be highly significant. According to Kayacetin (2019), there are germination obstacles in the black mustard seeds, and thus, there are difficulties in homogeneous, rapid, and simultaneous emergence.

Dormancy is an internal state of the seed that inhibits its germination. It is examined in two groups as primary and secondary dormancy. Primary dormancy refers to innate dormancy, and secondary dormancy refers to a dormant state induced in the nondormant seed by conditions inconvenient for germination. These reasons may be the cause of dormancy in the seeds of many weed species (Benech-Arnold et al., 2000). Dormancy and germination are vital phenomena in the life cycle of all species. Although the seeds vary considerably according to the species, they have different germination and dormancy characteristics according to their genetic structure (Gupta, 2016). Plant growth regulators such as PEG have been recommended to break seed dormancy and enhance germination (Bao et al., 2010; Luo et al., 2022; Hassan et al., 2023)

Seed priming is a simple and effective technology to help ensure homogeneous, simultaneous, and rapid emergence, thus leading to better crop yields (Finch-Savage and Bassel, 2016; Raj and Raj, 2019). Recently published studies showed that priming treatment can positively affect seed germination and seedling growth in the *Brassicaceae* family (Guragain et al., 2023; Kayacetin, 2023). As primed seeds are physiologically close to the germination stage, they show an improved germination percentage, early and uniform germination, improved growth characteristics, and faster and more homogeneous emergence (Fu et al., 2022; Okello et al., 2022). The Priming technique is one of the most effective options to shorten germination time and advence germination percentage to increase yield (Kayacetin, 2021; Thakur et al., 2022).

For the uniform emergence of the seed, osmopriming and hydropriming are the most effective methods (Singh et al., 2017; Pandey et al., 2022). The positive contributions of osmopriming on germination in sorghum (Zhang et al., 2015), in savory (Vidak et al., 2022), in wheat (Farooq et al., 2022), in sesame (Biswas and Dutta, 2021) and in black cumin (Kayacetin, 2022); whereas hydropriming on germination in mustard (Thapa et al., 2022), in sorghum (Demb´el´e et al., 2021), and in lemon balm (Hatami et al., 2021) have been previously reported.

Current and future work while focusing on the different uses of mustard plants and seeds, the negative effects on germination and emergence will be tried to be eliminated both in terms of breeding and agriculture. Information on enhancing the germination of black mustard against dormancy is still limited. Therefore, it was thought that the purpose of the research was to identify the effects of priming durations (12, 24, 36, and 48 h); unpriming, hydropriming, and five osmopriming doses (-0.1, -0.2, -0.4, 0.6, and -0.8 MPa of PEG) on seed germination and seedling establishment characteristics of black mustard (*Brassica nigra* L.) for 14 days on the dormancy-breaking and germination indices.

Material and Method
This study was done using pure line seeds of the *Brassica nigra*, obtained from the Research Institute in Ankara, Turkey (Table 1). The experimental design consisted of two factors (priming duration × seed treatment) regulated in a completely randomized design with three replicates. The osmotic potential of PEG-6000 was arranged at-0.2,-0.4,-0.6, and-0.8 MPa according to Michel and Kaufmann (1973). The priming durations (12, 24, 36, and 48 hours) were the main factors, seed treatments [unprimed (control), hydroprimed, and five osmoprimed doses (-0.1,-0.2,-0.4, 0.6, and-0.8 MPa of PEG)] was the subfactors. Samples of 150 seeds (three replicates of 50 seeds each) were placed in 9-cm Petri dishes containing two layers of filter paper.

Black mustard seeds were treated with immersed solution of -0.2, -0.4, -0.6, and -0.8 MPa polyethylene glycol for 12, 24, 36, and 48 hours and in distilled water (hydroprimed) for 12, 24, 36, and 48 hours. The unprimed seeds were used as control (unprimed). The seeds were carefully dried after priming to the first moisture level at 25 ± 3 °C and were and used 24 h after priming.

Seeds were kept at 22 ± 1 °C in the dark for germination for 14 days (Fallah-Toosi and Baki, 2013). Black mustard seed was considered to have germinated when >1 mm radicle emerged. Germination percentage was recorded every 24 h for 7 days. The mean germination time was numbered according to ISTA (2003). Shoot length, root length, seedling freshness and dry weight were evaluated in five seedlings selected randomly from each replicate after the 14th day. Dry weight was evaluated after drying samples in an oven at 70 °C for 48 h (Böhm, 1979). The final germination percentage (FGP) and mean germination time (MGT) were determined according to the method of Kader (2005).

$$\text{FGP (\%)} = \frac{\text{Total number of germinated seeds}}{\text{Total number of observed seeds}} \times 100$$

$$\text{MGT (day)} = \frac{\text{n1} \times \text{d1} + \text{n2} \times \text{d2} + \text{n3} \times \text{d3} + \cdots}{\text{Total number of days}}$$

n= number of seeds newly germinated at day;
d= days counted from the start of the germination test

Data statistical analysis

Analysis of variance of the experimental data was computed using the JMP 13 Statistical Software. The differences among the means were performed by LSD Test ($p < 0.05$).

Results and Discussion

The interaction effect of seed priming durations and seed priming treatment on final germination percentage (FGP), mean germination time (MGT), root length (RL), seedling length (SL), seedling fresh weight (SFW), and seedling dry weight (SDW) was significant (Table 2). While the maximum GP (97.33%) was obtained with the treatment of 12 and 24 h durations at -0.1 and -0.2 MPa of PEG priming, the minimum GP (64.67%) was determined with the treatment of 48 h durations at -0.8 MPa of PEG priming (Table 2). The maximum MGT (2.28 d) was obtained with unprimed, while the minimum MGT (1.17 d) was determined at -0.6 MPa of PEG for 48 h durations. The maximum RL (3.23 cm) and SL (6.21 cm) were obtained at -0.6 MPa and 0.4 MPa of PEG for 12 h durations, respectively, whereas the minimum RL (0.74 cm) and SL (2.36 cm) were obtained at -0.8 MPa of PEG for 48 h durations. The maximum SFW (8.28 mg) and SDW (0.71 mg) were obtained at -0.4 MPa for 12 h durations. The minimum SFW (0.83 mg) was determined at -0.8 MPa of PEG for 48 h durations. 48 h × -0.2 MPa of PEG priming and 48 h × -0.4 MPa PEG priming were detected at the minimum SDW (0.25 mg), and no significant differences were observed (Table 2). At the beginning of germination, rapid water uptake slows down after seed-based metabolic activities, resulting in the emergence of radicles leading to germination (Kayacetin, 2022). These results may explain that priming durations and treatments could improve theemergence performance of black mustard seeds, which is approved by earlier studies on some cultured species like black cumin (Kayacetin, 2022), sunflower (Bourioug et al., 2020), caraway (Mirmazloum et al., 2020), and kenaf (Lee et al., 2018). All priming processes used in this research made it possible to break dormancy in black mustard seeds considered dormant under appropriate conditions. Kayacetin (2023) demonstrated that osmo-priming treatments of black cumin using −0.2 or −0.4 MPa PEG for 24 or 36 hours demonstrated improved germination ability. Also, Trisnawaty et al. (2021) reported that different seed priming treatments resulted in significant seedling growth and reduced MGT in capers. In stevia, Shahverdi et al. (2017) demonstrated that PEG positively affected many aspects of plant growth, including seed germination and seedling growth. The rise in seedling growth traits with priming treatment could play a vital role in regulating plants's primary seedling growth. The major influence of the priming treatments was improved germination; therefore, post-germination progress could also be improved by priming seedling treatments. Considering seed priming treatments, it was noted that priming treatments improved seedling growth, which ended up with the maximum RL and SL. Kayacetin (2023) in black cumin noted that the maximum RL and SL were determined with the treatment of 36 h priming time at -0.4 MPa osmoprimed. This supports the idea that with priming treatments, the seed performs faster water uptake than normal germination. Previous studies showed that osmo and hydropriming achieved faster emergence and germination compared to control for germination (Neamatollahi et al., 2009; Kartika et al., 2021; Kayacetin, 2022; Bahreininejad, 2023).

A significant difference was detected among the priming durations for all the investigated characteristics (Table 3). While the maximum GP (91.24%) was obtained with the application of 24 h durations, the minimum GP (75.62%) was detected with the application of 48 h durations (Table 3). The minimum MGT (1.40 d) was determined with the application of 48 h durations, while the maximum MGT (1.61 d) was obtained within a 12 h duration. The maximum RL (2.23 cm) and SL (4.96 cm) were obtained for 12 and 36 h durations, respectively, whereas the minimum RL (1.19 cm) and SL (3.49 cm) were obtained for 48 h durations, respectively. The maximum SFW (5.41 mg) and SDW (0.46 mg) were obtained for 24 and 12 h durations, respectively. The minimum SFW (3.27 mg) and SDW (0.33 mg) weights were determined for 48 h durations (Table 3). While priming durations significantly increased the FGP and seedling growth parameters in black mustard seedlings, these parameters decreased by 48 h for the priming duration. At the onset of germination, rapid water uptake slows down after seed-based metabolic activities, resulting in the emergence of radicles leading to germination (Kayacetin, 2022). Therefore, 12 and 24 h are considered optimum duration for priming (Table 3). Kayacetin (2023) in black cumin found that 24 or 36 h priming treatment durations improved germination and seedling growth. Sadeghi et al. (2011) demonstrated that soybean seed osmopriming for 12 h improved the FGP. Mirmazloum et al. (2020) in caraway showed that 24 h priming duration was recommended as the best treatment for improving the FGP when compared to unprimed seeds. Benadjaoud et al. (2022) in *Lavandula stoechas* and Bahreininejad (2023) in *Thymus daenensis* reported that germination was positively affected by priming treatments compared to the unprimed. Mehra et al. (2003) determined that seeds of brown mustard and field mustard subjected to aerated hydration for up to 24 h had the most suitable timing at 12 h, which increased the final germination, and reduced MGT. Similar findings were observed by OrzeszkoRywka and Podlaski (2003) in sugar beet; Kayacetin, 2022 in black cumin with washing and priming that MGT was shortened by seed treatments.

A significant difference was determined among the priming treatments for all the investigated characteristics (Table 4). While the maximum GP (96.67%) and MGT (2.28 d) were obtained with unprimed applications, the minimum GP (72.67%) and MGT (1.37 d) were obtained with applications at -0.8 MPa of PEG priming (Table 4). The maximum RL (2.22 cm) and SL (5.11 cm) were obtained at -0.4 MPa and -0.1 MPa of PEG priming, respectively, whereas the minimum RL (1.35 cm) and SL (3.15 cm) were obtained at 0.8 MPa of PEG priming. The maximum SFW (6.00 mg) and SDW (0.49 mg) were obtained at -0.1 MPa of PEG priming and unprimed, respectively. The minimum SFW (3.23 mg) and SDW (0.36 mg) were determined at -0.8 MPa of PEG priming (Table 4). Whereas hydro and osmopriming treatments significantly increased the FGP and seedling growth parameters in black mustard seedlings compared to the unprimed, these parameters decreased by -0.6 and -0.8 MPa PEG osmopriming treatments, respectively. MGT was decreased by seed priming treatments and priming durations compared to unprimed ones. In black cumin, Kayacetin (2023) found that a -0.2 or -0.4 MPa priming treatment improved germination and seedling growth. Faijunnahar et al. (2009) in wheat seeds determined the most successful seedling growth with -0.1 MPa osmoprimed in comparison to unprimed. These outcomes are aided by Trisnawaty et al. (2021), who detected that rice seeds primed with PEG both improved germination indices and reduced MGT. Furthermore, results revealed that priming treatments were successful techniques to improve seed germination. Hydro and osmopriming of black mustard seeds also increased germination traits and seedling growth in the study.

Conclusions

The results showed that both priming durations and priming treatments of black mustard seeds significantly affected GP, MGT, RL, SL, SFW, and SDW compared to the unprimed. This positive effect, especially on germination, shortened the MGT. In terms of the properties studied, the optimal priming durations are 12 and 24 h; and priming treatments are hyropriming and osmopriming doses (-0.1, -0.2, and -0.4 Mpa of PEG). Results revealed that the applied priming treatments can be useful in improving the ability of black mustard in terms of germination treatments. It may be concluded that priming could end up being a very effective treatment to increase fast and identical emergence to accomplish better vigor, ending up with a better stand and yield. Therefore, current findings confirm that seed priming with PEG can be employed as a novel approach for improving black mustard seed germination efficiency. This technique is a practical pretreatment for fast and uniform emergence in unsuitable climatic conditions and can be used by researchers and farmers.

Table 1. Characteristics of the mustard species used in the study

Scientific name	Common name	Other name	Origin	Seed color	Thousand seed weight (g)	Registration
Brassica nigra	black mustard	*Sinapis nigra*	Ankara/Turkey	black-brown	1.4-1.6	pure line

Table 2. Effect of priming duration × priming treatment interaction on different germination parameters of black mustard

Priming durations	Priming treatment	GP (%)	MGT (day)	RL (cm)	SL (cm)	SFW (mg)	SDW (mg)
12	Unprimed	96.67 a	2.28 a	1.44 ij	4.31 fg	4.23 hi	0.49 b
	Hydroprimed	96.67 a	1.61 b	1.51 ij	4.25 fgh	4.33 h	0.35 g
	-0.1 MPa PEG primed	97.33 a	1.56 bc	1.73 hi	4.53 f	5.78 de	0.37 efg
	-0.2 MPa PEG primed	97.33 a	1.52 cd	2.65 bc	5.71 cd	6.01 cd	0.41 cde
	-0.4 MPa PEG primed	90.67 b	1.49 de	2.71 bc	6.21 b	8.29 a	0.71 a
	-0.6 MPa PEG primed	82.00 d	1.45 ef	3.23 a	5.99 bc	4.43 gh	0.49 b
	-0.8 MPa PEG primed	76.67 e	1.38 ghi	2.30 def	3.64 j	3.92 I	0.35 fg
24	Unprimed	96.67 a	2.28 a	1.44 ijk	4.31 fg	4.25 hi	0.49 b
	Hydroprimed	97.33 a	1.55 cd	1.72 hi	4.38 fg	4.78 fg	0.41 cde
	-0.1 MPa PEG primed	97.33 a	1.45 ef	2.40 c-f	5.10 e	5.91 cd	0.45 c
	-0.2 MPa PEG primed	97.33 a	1.53 cd	2.62 bc	4.88 e	5.95 cd	0.51 b
	-0.4 MPa PEG primed	90.67 b	1.51 cde	2.82 b	6.18 b	6.24 bc	0.43 cd
	-0.6 MPa PEG primed	82.67 cd	1.41 fgh	2.18 fg	5.90 bc	5.90 cd	0.41 cde
	-0.8 MPa PEG primed	76.67 e	1.45 ef	1.14 kl	3.48 jk	4.85 f	0.40 de
36	Unprimed	96.67 a	2.28 a	1.44 ijk	4.31 fg	4.23 hi	0.49 b
	Hydroprimed	92.67 b	1.42 fg	2.58 bcd	6.80 a	5.12 f	0.39 def
	-0.1 MPa PEG primed	90.67 b	1.29 jkl	2.53 b-e	6.69 a	6.44 b	0.43 cd
	-0.2 MPa PEG primed	85.33 c	1.24 lm	2.22 efg	5.54 d	5.48 e	0.51 b
	-0.4 MPa PEG primed	85.33 c	1.35 hij	2.10 fg	4.25 fgh	4.78 fg	0.41 cde
	-0.6 MPa PEG primed	76.00 e	1.29 kl	1.96 gh	3.97 hi	4.44 gh	0.21 j
	-0.8 MPa PEG primed	72.67 f	1.41 fgh	1.22 jkl	3.13 l	3.30 j	0.39 def
48	Unprimed	96.67 a	2.28 a	1.44 ijk	4.31 fg	4.24 hi	0.49 b
	Hydroprimed	62.67 h	1.32 ijk	1.26 jkl	3.69 ij	4.34 h	0.35 fg
	-0.1 MPa PEG primed	83.33 cd	1.33 ijk	1.22 jkl	4.13 gh	5.85 d	0.41 cde
	-0.2 MPa PEG primed	81.33 d	1.27 kl	1.29 jkl	3.47 jk	4.35 h	0.25 ij
	-0.4 MPa PEG primed	72.67 f	1.21 mn	1.26 jkl	3.24 kl	2.04 k	0.25 ij
	-0.6 MPa PEG primed	68.00 g	1.17 n	1.11 l	3.24 kl	1.26 l	0.30 h
	-0.8 MPa PEG primed	64.67 h	1.24 lm	0.74 m	2.36 m	0.83 m	0.27 hi
Summary of ANOVA	**	**	**	**	**	**	

** Significant at $p < 0.05$

Table 3. Effect of priming duration on different germination parameters of black mustard

Priming durations (h)	GP (%)	MGT (day)	RL (cm)	SL (cm)	SFW (mg)	SDW (mg)
12	91.05 a	1.61 a	2.23 a	4.94 a	5.30 a	0.46 a
24	91.24 a	1.60 a	2.05 b	4.89 a	5.41 a	0.44 a
36	85.62 b	1.47 b	2.01 b	4.96 a	4.83 b	0.41 b
48	75.62 c	1.40 c	1.19 c	3.49 b	3.27 c	0.33 c
Summary of ANOVA	**	**	**	**	**	**

** Significant at $p < 0.05$

Table 4. Effect of priming treatment on different germination parameters of black mustard

Priming treatment	GP (%)	MGT (day)	RL (cm)	SL (cm)	SFW (mg)	SDW (mg)
Unprimed	96.67 a	2.28 a	1.45 d	4.29 d	4.26 d	0.49 a
Hydroprimed	87.33 d	1.48 b	1.77 c	4.78 c	4.64 c	0.38 d
-0.1 MPa PEG primed	92.17 b	1.41 c	1.97 b	5.11 a	6.00 a	0.42 c
-0.2 MPa PEG primed	90.33 c	1.39 cd	2.20 a	4.90 bc	5.45 b	0.42 c
-0.4 MPa PEG primed	84.83 e	1.39 cd	2.22 a	4.97 ab	5.34 b	0.45 b
-0.6 MPa PEG primed	77.17 f	1.33 e	2.12 ab	4.77 c	4.01 e	0.35 e
-0.8 MPa PEG primed	72.67 g	1.37 d	1.35 d	3.15 e	3.23 f	0.36 de
Summary of ANOVA	**	**	**	**	**	**

** Significant at $p < 0.05$

Data Availability Statement

The data are available on request.

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Statement of Conflict of Interest

The author(s) declare no conflict of interest for this study.

Author's Contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

Asaduzzaman, M. Huqe, M.A.S. Haque, M.S. Uddin, M.N. Hossain, M.A. (2021). Seed priming improves germination and early seedling growth in wheat under control and drought conditions. Journal of Bangladesh Agricultural University, 19, 2, 184-191.

Bahreininejad, B. (2023). A predictive method for selecting the most appropriate level of water potential for *Thymus daenensis* ssp. daenensis Cleak seed priming with respect to the severity of salinity or drought stress. Journal of Applied Research on Medicinal and Aromatic Plants, 34, 100453. https://doi.org/10.1016/j.jarmap.2022.100453

Bao, J.P. Zhang, S.L. (2010). Effects of seed coat, chemicals and hormones on breaking dormancy in pear rootstock seeds (*Pyrus betulaefolia* Bge. and *Pyrus calleryana* Dcne.). Seed Science and Technology, 38, 2, 348-357.

Benadjaoud, A. Dadach, M. El-Keblawy, A. and Mehdadi, Z. (2022). Impacts of osmopriming on mitigation of the negative effects of salinity and water stress in seed germination of the aromatic plant *Lavandula stoechas* L. Journal of Applied Research on Medicinal and Aromatic Plants, 31, 100407.

Benech-Arnold, R.L. Sánchez, R.A. Forcella, F. Kruk, B.C. Ghersa, C.M. (2000). Environmental control of dormancy in weed seed banks in soil. Field Crops Research, 67, 2, 105-122.

Biswas, U. Dutta, A. (2021). Influence of pre-sowing seed priming and packaging materials on the quality of sesame (*Sesamum indicum* L.) seeds. 23, 4, 389-395. https://doiorg/10.5958/0974-4517.2021.00049.5

Bourioug, M. Ezzaza, K. Bouabid, R. Alaoui-Mhamdi, M. Bungau, S. Bourgeade, P. Aleya, L. (2020). Influence of hydro-and osmo-priming on sunflower seeds to break dormancy and improve crop performance under water stress. Environmental Science and Pollution Research, 27, 13215-13226.

Böhm, W. (1979). Methods of Studying Root Systems, Springer-Verlag, Berlin.

Darwesh, D.T.D. (2017). Plant Biodiversity and Ethnobotanical Properties of

Various Plants in Choman (Erbil-Iraq) (Doctoral dissertation. 130pp, MSc, Sutcu Imam University, Kahramanmaras, Turkey.
Dembélé, S. Zougmoré, R.B. Coulibaly, K. Lamers, J.P. Tetteh, J.P. (2021). Accelerating seed germination and juvenile growth of sorghum (*Sorghum bicolor* L. Moench) to manage climate variability through hydro-priming. Atmosphere, 12, 4, : 419.
Fallah-Toosi, A. Baki, B.B. (2013). Effect of NaCl on germination and early seedling growth of *Brassica juncea* var. Ensabi. International Journal of Agronomy and Plant Production, 4, 11, 3004-3011.
Farooq, T. Nisa, Z.U. Hameed, A. Ahmed, T. and Hameed, A. (2022). Priming with copper-chitosan nanoparticles elicit tolerance against PEG-induced hyperosmotic stress and salinity in wheat. BMC chemistry, 16, 1, 23.
Finch-Savage, W.E. Bassel, G.W. (2016) Seed vigour and crop establishment: extending performance beyond adaptation. J Exp Bot 67, 567- 591.
Gupta, S.K. (Ed.). (2016). Biology and breeding of crucifers. CRC Press.
Guragain, R.P. Baniya, H.B. Shrestha, B. Guragain, D.P. Subedi, D.P. (2023). Germination enhancement of mustard (*Brassica nigra*) seeds using dielectric barrier discharge (DBD). AIP Advances, 13(3).
Hassan, F.E. Alyafei, M.A. Kurup, S. Jaleel, A. Al Busaidi, N. and Ahmed, Z.F. (2023). Effective Priming Techniques to Enhance Ghaf (*Prosopis cineraria* L. Druce) Seed Germination for Mass Planting. Horticulturae, 9, 5, 542.
Hatami, M. Khanizadeh, P. Abtahi, F.A. Abaszadeh Dehgi, P. (2021). Influence of plant growth promoting rhizobacteria and hydro-priming on some physiological indices of lemon balm (*Melissa officinalis*). Iranian Journal of Horticultural Science, 52, 1, 11-21.
ISTA. (2003). ISTA Handbook on seedling evaluation. 3rd ed. International Seed Testing Association (ISTA), Zurich, Switzerland.
Kader, M.A. (2005). A comparison of seed germination calculation formulae and the associated interpretation of resulting data. Journal and Proceeding of the Royal Society of New South Wales, 138, 65-75.
Kartika, K. Lakitan, B. Ria, R.P. (2021). Hydro-and osmo-priming effects on upland rice exposed to drought conditions at vegetative and reproductive stages. CMUJ. Nat. Sci., 20, 3, e2021053.
Kayacetin, F. (2020). Botanical characteristics, potential uses, and cultivation possibilities of mustards in Turkey: a review. Turkish Journal of Botany, 44, 2, 101-127. https://doi.org/10.3906/bot-1909-30
Kayacetin, F. (2019). Morphological characterization and relationships among some important wild and domestic Turkish mustard genotypes (*Brassica* spp.). Turkish Journal of Botany, 43, 4, 499-515. https://doi.org/10.3906/bot-1810
Kayacetin, F. (2021). Selection of some important species in genus Brassica against drought and salt tolerance by morphological observations on germination and seedling growth parameters. Fresenius Environmental Bulletin, 30, 7 A, 9228-9236.
Kayacetin, F. (2022). Response to Direct Selection against drought stress in black cumin (*Nigella sativa* L.). Evidence-Based Complementary and Alternative Medicine, 2022, Article ID 6888187, 1-10. https://doi.org/10.1155/2022/6888187.
Kayacetin, F. Efeoglu, B. Alizadeh, B. (2018). Effect of NaCl and PEG-Induced osmotic stress on germination and seedling growth properties in wild mustard (*Sinapis arvensis* L.). ANADOLU Ege Tarımsal Araştırma Enstitüsü Dergisi, 28, 1, 62-68.
Kinay, A., Kayacetin, F. (2023). Phenology, morphology, yield and quality characteristics of mustard species (*Brassica* spp.) suitable for energy sector. Gesunde Pflanzen, 1-10. https://doi.org/10.1007/s10343-022-00817-w
Lee, I. S. Kang, C.H. Kwon, S.J. Na, Y.E. (2018). Effects of PEG priming and fungicide treatment on kenaf (*Hibiscus cannabinus* L.) seed germination. Journal of Agricultural Science and Technology, B, 278-289. https://doi.org/10.17265/2161-6264/2018.05.002
Lietzow, J. (2021). Biologically active compounds in mustard seeds: A toxicological perspective. Foods, 10, 9, 2089. https://doi.org/10.3390/foods10092089
Luo, J.M. Liu, H. Wang, J.L. Liu, Y.F. Wang, Q.Y. Huang, Y. (2022). Screening and evaluation of methods for breaking seed dormancy of wild Artemisia wellbyi. Acta Agrestia Sinica, 30, 6, 1603. https://doi.org/10.11733/j.issn.1007-0435.2022.06.035
Mayekar, V.M. Ali, A. Alim, H. Patel, N. (2021). A review: Antimicrobial activity of the medicinal spice plants to cure human disease. Plant Science Today 8, 3, 629-646. https://doi.org/10.14719/pst.2021.8.3.1152
Mehra, V. Tripathi, J. Powell, A.A. (2003). Aerated hydration treatment improves the response of *Brassica juncea* and *Brassica campestris* seeds to stress during germination. Seed Science and Technology, 31, 1, 57-70.
Michel, B.E. Kaufmann, M.R. (1973). The osmotic potential of polyethylene glycol 6000. Plant Physiol., 51, 914-916.
Mirmazloum, I. Kiss, A. Erdélyi, É. Ladányi, M. Németh, É. Z. Radácsi, P. (2020). The Effect of osmopriming on seed germination and early seedling characteristics of *Carum carvi* L. Agriculture, 10, 4, 94. https://10.3390/agriculture10040094
Neamatollahi, E. Bannayan, M. Darban, A.S. Ghanbari, A. (2009). Hydropriming and osmopriming effects on cumin (Cuminum Cyminum L.) seeds germination. International Journal of Agricultural and Biosystems Engineering, 3(9), 477-480. https://doi.org/10.12982/CMUJNS.2021.053
Nisar, NS. Mehmodd, H. Nisar, S. Jamil, Z. Ahmad, N. Ghani, N. Oladipo, A.A. Waseem, R.Q. Latif, A.A. Ahmad, S.R. Iqbal, M. Abbas, M. (2018). *Brassicaceae* family oil methyl esters blended with ultra-low sulphur diesel fuel (ULSD): Comparison of fuel properties with fuel standards. Renewable Energy 117: 393-403. https://doiorg/101016/jrenene201710087
Okello, D. Komakech, R. Gang, R. Rahmat, E. Chung, Y. Omujal, F. Kang, Y. (2022). Influence of various temperatures, seed priming treatments and durations on germination and growth of the medicinal plant Aspilia africana. Scientific Reports, 12, 1, 14180. https://doi.org/10.1038/s41598-022-18236-2
Orzeszko-Rywka, A. Podlaski, S. (2003). The effect of sugar beet seed treatments on their vigour. Plant Soil and Environment, 49, 6, 249-254.
Palle-Reisch, M. Wolny, M. Cichna-Markl, M. and Hochegger, R. (2013). Development and validation of a real-time PCR method for the simultaneous detection of black mustard (*Brassica nigra*) and brown mustard (*Brassica juncea*) in food. Food Chemistry, 138, 348-355. https://doi.org/10.1016/j.foodchem.2012.10.055
Pandey, S. Oza, K. Maitreya, B. (2022). Effect of different solutions on seed germination and growth of different species of seeds review. International Association of Biologicals and Computational Digest, 1, 2, 168-172. https://doi.org/10.1371/journal.pone.0140620
Raj, A.B. and Raj, S.K. (2019). Seed priming: An approach towards agricultural sustainability. Journal of Applied and Natural science, 11, 1, 227-234. https://doi.org/10.31018/jans.v11i1.2010
Sadeghi, H. Khazaei, F. Yari, L. Sheidaei, S. (2011). Effect of seed osmopriming on seed germination behavior and vigor of soybean (*Glycine max* L.). ARPN Journal of Agricultural and Biological Science, 6, 1, 39-43.
Shahverdi, M.A. Omidi, H. Tabatabaei, S.J. (2017). Effect of nutri-priming on germination indices and physiological characteristics of stevia seedling under salinity stress. Journal of Seed Science, 39, 353-362. https://doi.org/10.1590/2317-1545v39n4172539
Singh, S. Lal, G.M. Bara, B.M. Mishra, S.N. (2017). Effect of hydropriming and osmopriming on seed vigour and germination of Pea (*Pisum sativum* L.) seeds. J. Pharmacognosy and Phytochemistry, 6, 3, 820-824.
Thakur, M. Tiwari, S. Kataria, S. Anand, A. (2022). Recent advances in seed priming strategies for enhancing planting value of vegetable seeds. Scientia Horticulturae, 305, 111355. h
Thapa, S. Baral, B. Shrestha, M. Dahal, D.K.C. (2022). Effect ff different priming methods on germination behaviour of broadleaf mustard cv. marpha chauda paate. Tropical Agrobiodiversity (TRAB), 3, 2, 52-59. http://doi.org/10.26480/trab.02.2022.52.59
Trisnawaty, A.R. Asra, R. Panga, N.J. Sjahril R. (2021). Effect of osmo-priming with polyethylene glycol 6000 (PEG-6000) on rice seed (*Oryza sativa* L.) germination and seedling growth under drought stress," International Journal of Agriculture System, 9, 1, 40-50. https://doi.org/10.20956/ijas.v9i1.2558
Vidak, M. Lazarević, B. Nekić, M. Šatović, Z. Carović-Stanko, K. (2022). Effect of hormonal priming and osmopriming on germination of winter savory (*Satureja montana* L.) natural population under drought stress. Agronomy, 12, 6, 1288. https://doi.org/10.3390/agronomy12061288
Zhang, F. Yu, J. Johnston, C.R. Wang, Y. Zhu, K. Lu, F. Zhang, Z Zou, J. (2015). Seed priming with polyethylene glycol induces physiological changes in sorghum (*Sorghum bicolor* L. Moench) seedlings under suboptimal soil moisture environments. PLoS One, 10(10), e0140620. https://doi.org/10.1371/journal.pone.0140620 42.