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Effects of Some Temperature and Dormancy-Breaking Applications on Germination Rates of Camelthorn (*Alhagi pseudalhagi* (Bieb.) Desv.) Seeds

Deve Dikeni (*Alhagi pseudalhagi* (Bieb.) Desv.) Tohumlarının Çimlenme Oranları Üzerine Bazı Sıcaklık ve Dormansi Kırma Uygulamalarının Etkileri

Bilal KESKİN
Süleyman TEMEL
Gülüm GÜREL
Eren ÖZDEN

[1]Department of Field Crops, Iğdır University, Faculty of Agriculture, Iğdır, Turkey
[2]Department of Horticulture, Faculty of Agriculture, Iğdır University, Iğdır, Turkey

ABSTRACT

This study was carried out to determine the effects of some temperatures and dormancy-breaking applications on seed germination rates of camelthorn (*Alhagi pseudalhagi*) seeds. The research was carried out in the Field Crops Laboratory of the Faculty of Agriculture of Igdir University in 2020. Camelthorn seeds were initially germinated in dark at 10°C, 15°C, 20°C, and 25°C constant and at 20/10°C, 20/15°C, 25/10°C, and 25/15°C variable temperature conditions. It was determined that the highest total and normal germination rates were 33.3% and 28.0%, respectively, at 25/15°C conditions, and the abnormal germination rate was 14.6% at 20/10°C conditions. It was observed that no germination took place in the seeds under constant temperature conditions of 10°C. It was determined that 66.7% of *A. pseudalhagi* seeds had a dormancy-related germination problem even under the best temperature conditions. For this purpose, 12 different dormancy-breaking applications (matrix-priming, hydro-priming, gibberellic acid, potassium nitrate, cold moist stratification, warm moist stratification, warm + cold moist stratification, cold + warm moist stratification, cold water, hot water, mechanical scarification, and chemical scarification (sulfuric acid)) were made to *A. pseudalhagi* seeds. According to the results of the research, it was determined that gibberellic acid 28.0%, hot water 25.4%, and mechanical scarification 18.7% removed the dormancy in seeds.

Keywords: *Alhagi pseudalhagi*, camelthorn, dormancy breaking, seed dormancy, seed germination, temperature

ÖZ

Bu çalışma, Deve dikeni (*Alhagi pseudalhagi*) tohumlarının çimlenmesi üzerine bazı sıcaklıkların ve dormansi kırma uygulamalarının etkilerini belirlemek amacıyla yapılmıştır. Araştırma Iğdır Üniversitesi Ziraat Fakültesi Tarla Bitkileri Laboratuvarında 2020 yılında yürütülmüştür. Tohumlar başlangıçta 10, 15, 20 ve 25°C sabit ve 20/10°C, 20/15°C, 25/10°C, ve 25/15°C değişken sıcaklık koşullarında karanlık ortamda çimlendirmeye alınmıştır. En yüksek toplam ve normal çimlenme oranlarının sırasıyla %33,3 ve %28,0 olarak 25/15°C koşullarında, anormal çimlenme oranının ise %14,6 ile 20/10°C koşullarında olduğu belirlenmiştir. Tohumların 10°C sabit sıcaklık koşullarında ise herhangi bir çimlenmesinin gerçekleşmediği görülmüştür. *Alhagi pseudalhagi* tohumlarında en iyi sıcaklık koşullarda bile %66,7 oranında dormansiye bağlı bir çimlenme problemi olduğu belirlenmiştir. Bu amaçla *Alhagi pseudalhagi* tohumlarına 12 farklı dormansi kırma uygulaması (matrik-priming hidro-priming, giberellik asit, potasyum nitrat, soğuk katlama, sıcak katlama, sıcak + soğuk katlama, soğuk + sıcak katlama, soğuk su, sıcak su, mekanik aşındırma, ve kimyasal aşındırma (sülfürik asit)) yapılmıştır. Araştırma sonuçlarına göre, giberellik asitin %28,0, sıcak suyun %25,4, ve mekanik aşındırmanın %18,7 oranında tohumlardaki dormansiyi kaldırdığı belirlenmiştir.

Anahtar Kelimeler: *Alhagi pseudalhagi*, sıcaklık, deve dikeni, dormansi kırma, tohum dormansisi, tohum çimlenmesi

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Sorumlu Yazar/Corresponding Author: Bilal KESKİN
E-mail: bilalkeskin66@yahoo.com

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Introduction

Plants have important values not only in the nutrition of humans and animals but also in the treatment of diseases, thanks to the secondary metabolites they contain such as alkaloids, phenolic compounds, glycosides, and steroids. The genus *Alhagi*, which is included in the legume family, is widespread in many countries in Asia, America, Africa, Europe, and Australia (Ali, 1977; Ghosal et al., 1974; Liu & Adilla, 1991; Muhammad et al., 2015; Smailov et al., 1990). Species in this genus are widely used in weed, animal feed, erosion control, and pharmaceutical industries, and many scientific studies have been carried out for this purpose (Awaad et al., 2006; Ibrahim, 2015; Muhammad et al., 2015). Important fatty acids, sterols, flavonoids, coumarins, and alkaloids have been identified in species belonging to the genus *Alhagi* (Awaad et al., 2006; Edeoga et al., 2005; Ibrahim, 2015). Most of the species in the genus *Alhagi* are commonly used for medicinal purposes (Gholamhoseinian & Razmi, 2012; Kouchmeshky et al., 2012; Laghari et al., 2012a,b; Srivastava et al., 2014; Zou et al., 2012).

The protein content of the *Alhagi pseudalhagi* plant varies between 12.8% in the early vegetative stage and 10.8% in the seed maturation stage (Temel et al., 2015). On the other hand, the high mineral content and low NDF (Neutral Detergent Fiber) and ADF (Acid Detergent Fiber) values increase the value of animal feed (Muhammad et al., 2015; Temel et al., 2015).

Although *A. pseudalhagi* is widely found in natural environments, there is not enough information about the use and cultivation of the plant. *A. pseudalhagi* plant is spiny deep-rooted and perennial shrub whose roots can grow up to 1.8–2.1 m deep into the soil and can reach a plant height of up to 0.45–1.2 m (Sulaiman, 2013; Tan & Temel, 2012). *A. pseudalhagi* is an important plant because it remains green for most of the year, is resistant to drought and salinity, is found in erosion areas, and has a high potential for medicinal use. In addition, it is a plant that has the potential to be used in the evaluation of salinity, arid, and degraded pasture areas.

The seeds of plants grown in their natural environments are used for production and breeding (Akan et al. 2008). Generally, a high rate of dormancy is observed in seeds collected from nature. Therefore, before these seeds are cultivated, the germination and dormancy status of the seeds should be determined. In this study, it was tried to determine the ideal germination temperature, dormancy status of *A. pseudalhagi* seeds, which have the potential to be widely used in animal feed and medicine, in the evaluation of arid and salinity areas, and which dormancy-breaking application increase seed germination rates in order to eliminate this dormancy.

Methods

A. pseudalhagi seeds, which were used as test material, were collected from the wind erosion area of the Iğdır province, Aralik district. Then, the collected seeds were stored at 5°C in airtight packages until the viability tests were carried out. Laboratory studies were carried out in Igdir University Faculty of Agriculture, Field Crops Department laboratory in 2020 according to the Random Plots Trial Design with three replications.

Germination Test

Seeds were germinated in a dark environment at constant temperatures of 10°C, 15°C, 20°C, and 25°C and variable temperatures of 20/10°C, 20/15°C, 25/10°C, and 25/15°C. A total of 3 × 25 seeds were used in each germination application. The germination status of the seeds was followed daily for 28 days at the temperatures determined between the germination papers impregnated with water in a 120 × 20 mm glass petri dish. In order to prevent fungus growth, 0.2% pomarsol was added to the pure water given to the germination medium. The germination status of the seeds was followed for 28 days, and the seeds showing radicula length of 2 mm and above were considered viable (ISTA, 2017). Total, normal, and abnormal germination rate of seeds were determined at the end of the 28th day of the experiment.

According to ISTA (International Seed Testing Association,2017) rules, 12 different dormancy-breaking processes were applied to the seeds of the *A. pseudalhagi* plant. After the dormancy-breaking applications, the germination rates of the seeds were determined daily for 28 days at the temperature where the highest germination rates were determined. In the study, 3 replications and 25 seeds were used in each replication.

Matrix-Priming

Matrix-priming (MP) medium was prepared in light-proof containers in the form of seed:vermiculite:water medium in the ratio 2:1:3. Matrix-priming's were incubated for 24, 36, and 48 hours at 15°C, and then seeds were dried to their initial weight at 25°C.

Hydro-Priming

The seeds were kept in 40 mL of water for 5 hours at 20°C, and then surface drying was applied to the seeds. After the surface drying process, some water was put into the aging pots, and the seeds were placed in a shirred tulle pouch on the wire tray so that they would not come into contact with the water. The upper part of the aging pots is covered with stretch so that there is no air intake. The aging pots were incubated at 20°C for 48, 72, and 96 hours, and then the seeds removed from the aging pots were dried to their initial weight at room temperature.

Gibberellic Acid

The seeds were kept in gibberellic acid (GA_3) solution prepared as 250, 500, and 1000 ppm in a petri dish for 24 hours in dark conditions and then the seeds were dried to their initial weight at room temperature.

Potassium Nitrate

Seeds were kept in a petri dish in 2% and 4% potassium nitrate (KNO_3) solutions in dark conditions for 6 hours.

Cold Moist Stratification

The seeds were kept between filter papers saturated with moisture for 3 and 4 weeks at 5°C temperature conditions, and then the seeds were dried to their initial weight at room temperature.

Warm Moist Stratification

The seeds were kept between filter papers saturated with moisture for 1 and 2 weeks at 20°C temperature conditions, and then the seeds were dried to their initial weight at room temperature.

Warm + Cold Moist Stratification

The seeds were kept between coarse filter papers saturated with sufficient moisture for 1 and 2 weeks at 20°C temperature conditions and then at 5°C for 3 and 4 weeks and then dried to their initial weight at room temperature.

Cold + Warm Moist Stratification

Seeds were stored between coarse filter papers saturated with sufficient moisture at 5°C for 3 and 4 weeks, followed by 1 and

2 weeks at 20°C, and then the seeds were dried to their initial weight at room temperature.

Cold Water
Seeds placed in a shirred tulle pouch were kept in glass bottles at 5°C for 1, 2, and 4 weeks, completely submerged in water, and then the seeds were dried at room temperature to their initial weight.

Hot Water
Seeds placed in a shirred tulle pouch were kept in boiling water (100°C) for 2 and 4 minutes to be completely submerged, and then the seeds were dried at room temperature to their initial weight.

Mechanical Scarification
The seeds were scarification for 5, 10, and 15 minutes between 10 grit sandpapers.

Chemical Scarification (Sulfuric Acid)
The seeds were kept in 96% sulfuric acid (H_2SO_4) for 10, 20, and 30 seconds, and then the seeds were washed with distilled water and dried on blotting paper.

Statistical Analysis
The data obtained from the research were analyzed according to the JMP 5.0.1 package program. Statistically significant means were grouped according to the least significance difference.

Results, Discussion, and Conclusion and Recommendations

Germination Rates of *A. pseudalhagi* at Different Constant and Alternating Temperatures

It was determined that germination at different temperatures significantly affected the germination rates of *A. pseudalhagi* seeds (Table 1). It was observed that the total and normal germination rates of the seeds at 25/15°C temperature conditions reached the highest values as 33.3% and 28.0%, respectively. Even at the temperature at which the highest germination rate was obtained, 66.7% dormancy was determined in *A. pseudalhagi* seeds. It is known that dormancy is generally high in plants that grow in natural environments (Esmaili & Esmaili, 2010; İkram et al., 2014; Tavili et al., 2014; Zhou et al., 2012). No germination was observed in *A. pseudalhagi* seeds under the lowest temperature application, 10°C. The highest rate of abnormal germination was observed in seeds germinated at 25/10°C conditions (Table 1). It is known that seeds can germinate at a higher rate in variable temperature conditions than in constant temperature conditions, as an indicator of mimicking their natural life cycles (Ozden et al. 2021).

Studies have reported that the highest germination conditions of *A. pseudalhagi* and *Alhagi camelorum* seeds are in the range of 25–35°C temperatures (Moradi et al., 2015; Solak et al., 2015). It is known that there is 81% dormancy in *A. camelorum* seeds (Solak et al., 2015), and dormancy rates reach up to 98.9% in studies on *A. pseudalhagi*, *Alhagi cancencens*, *Alhagi kirghisorum*, and *Alhagi sparsifolia* species (Karshibaev, 2014). Seeds of *Alhagi* species generally have a high dormancy rate, and the optimum germination temperature was determined to be 25°C. The presence of dormancy in seeds in natural environments is the guarantee of the continuity of the plant. However, dormancy is undesirable in the seeds of cultivated plants, since high dormancy will increase the amount of seeds to be sowed per unit area and will develop as an undesirable plant in the field in the following years.

Table 1.
Germination Rates of Alhagi pseudalhagi at Different Constant and Alternating Temperatures

Temperature	Total Germination (%)	Normal Germination (%)	Abnormal Germination (%)
10°C	0.0 f	0.0 e	0.0 c
15°C	8.0 e	2.6 de	5.3 bc
20°C	10.6 de	6.6 d	4.0 bc
25°C	25.3 b	16.0 bc	9.3 ab
20/10°C	14.6 cd	0.0 e	14.6 a
20/15°C	17.3 c	14.6 c	2.6 bc
25/10°C	30.6 ab	21.3 b	9.3 ab
25/15°C	33.3 a	28.0 a	8.3 bc
LSDs	6.4**	6.5**	7.8*

Note: LSD = Least significance difference.
*$p < .05$ significant at probability limits, **$p < .01$ significant at probability limits.

Germination Rates of *A. pseudalhagi* in Dormancy-Breaking Treatments

Matrix-Priming. In previous literature studies, no MP application was found in seeds of *Alhagi* species. In our current study, *A. pseudalhagi* seeds were exposed to MP at different times, but the effect of MP applications on seed germination rates was not found to be statistically significant (Table 2). On the other hand, in studies on different plant species (*Allium cepa*, *Abelmoschus esculentus*, *Abelmoschus esculentus*, and *Allium ampeloprasum*), it is known that MP applications can allow increases in seed germination rate compared to control (Ozden et al., 2018a,b; Pandita et al., 2010). In the current study, it was seen that MP applications were not effective in breaking dormancy in *A. pseudalhagi* seeds compared to the control application.

Hydro-Priming. Hydro-priming (HP) treatments at different times significantly affected the total, normal, and abnormal germination rates of *A. pseudalhagi* seeds. Depending on the increase in the application time of HP, there was a decrease in the total germination rates. The highest total germination rate was obtained from 48 hours of HP application. Due to the high rate of abnormal germination (9.3%) in 48 and 96 hours of HP, the highest normal germination rate was obtained from 72 hours of HP (Table 2).

It is known that HP applications are applied only to *Alhagi maurorum* seeds among *Alhagi* species, and Anosheh (2020) stated that HP applications are effective in breaking dormancy in *A. maurorum* seeds. On the other hand, it is known that HP applications to some species such as *Nigella sativa*, *Allium cepa*, and *Lactuca sativa* contribute to the breaking of dormancy in seeds (Ozden et al., 2018a; Rao et al., 1987; Tajbakhsh et al., 2014).

Gibberellic Acid. Gibberellic acid application to *A. pseudalhagi* seeds statistically affected the total and normal germination rates. Application of GA_3 at low concentrations (250 ppm) caused an increase in germination rates, while application of GA_3 at higher concentrations (500 and 1000 ppm) caused a gradual decrease in germination rates of seeds. On the other hand, the effect of GA_3 application on abnormal germination rates was not found significant (Table 2).

In the seeds of *Alhagi* species, GA_3 applications were not found in order to break dormancy. In studies on some other species, it has been revealed that the application of GA_3 applied to seeds

Table 2.
Effects of Some Dormancy-Breaking Treatments on Seed Germination of Alhagi pseudalhagi

Applications	Treatments	Total Germination (%)	Normal Germination (%)	Abnormal Germination (%)
Matrix-priming	24 hours	36.0	33.3	2.6
	36 hours	30.6	25.3	5.3
	48 hours	37.3	32.0	5.3
LSD value and significant		9.8 ns	14.7 ns	6.1 ns
Hydro-priming	48 hours	44.0 a	34.6 a	9.3 a
	72 hours	40.0 ab	40.0 a	0.0 b
	96 hours	26.6 b	17.3 b	9.3 a
LSD value and significant		14.2*	14.8**	3.0**
Gibberellic acid	250 ppm	61.3 a	50.7 a	10.7
	500 ppm	49.3 b	37.3 b	12.0
	1000 ppm	38.7 c	32.0 b	6.7
LSD value and significant		3.0**	7.4**	6.1 ns
Potassium nitrate	2%	24.0 b	18.6	5.3
	4%	41.3 a	28.0	13.3
LSD value and significant		11.5*	15.2 ns	9.9 ns
Cold moist stratification	3 weeks	9.3 b	8.0 b	1.3
	4 weeks	49.3 a	46.6 a	2.7
LSD value and significant		5.7**	5.7**	5.7 ns
Warm moist stratification	1 week	14.7 b	12.0 b	2.6
	2 weeks	44.0 a	38.6 a	5.3
LSD value and significant		25.0*	15.2**	11.5 ns
Warm + cold moist stratification	1 week + 3 weeks	24.0 c	21.3	2.7 b
	1 week + 4 weeks	32.0 b	32.0	0.0 b
	2 weeks + 3 weeks	40.0 a	21.3	18.7 a
	2 weeks + 4 weeks	26.7 bc	24.0	2.7 b
LSD value and significant		6.9**	10.9 ns	6.9**
Cold + warm moist stratification	3 weeks + 1 week	32.0 bc	25.3 a	6.7
	3 weeks + 2 weeks	25.3 c	16.0 b	9.3
	4 weeks + 1 week	40.0 a	28.0 a	12.0
	4 weeks + 2 weeks	33.3 ab	24.0 a	9.3
LSD value and significant		7.4**	6.5**	5.5ns
Cold water	1 week	25.3 b	22.7 ab	2.6
	2 weeks	41.3 a	36.0 a	5.3
	4 weeks	14.7 b	12.0 b	2.6
LSD value and significant		12.1**	17.6*	6.1 ns
Hot water	2 minutes	58.7 a	36.0 a	22.6 a
	4 minutes	24.0 b	9.3 b	14.7 b
LSD value and significant		28.7*	11.5**	5.7**
Mechanical scarification	5 minutes	33.3 b	30.7	2.7 b
	10 minutes	36.0 b	26.7	9.3 a
	15 minutes	52.0 a	38.7	13.3 a
LSD value and significant		10.3**	12.8 ns	6.1**
Chemical scarification	10 seconds	36.0	24.0	12.0
	20 seconds	32.0	25.3	6.7
	30 seconds	37.3	28.0	9.3
LSD value and significant		10.3 ns	4.8 ns	8.3 ns

Note: LSD = Least significance difference; ns = Not significant.
*$p < .05$ significant at probability limits, **$p < .01$ significant at probability limits.

at concentrations ranging from 100 to 1000 ppm is an effective method in breaking dormancy (Akkurt et al., 2013; Gökçöl & Duman, 2018; Keshtkar et al., 2008; Kırmızı, 2017; Okay & Günöz, 2009; Zhou et al., 2012). On the other hand, some studies have shown that it is not effective in breaking dormancy (Açıkgöz et al., 2019; Çolak, 2011; Erken et al., 2014; İkram et al., 2014). On the other hand, Çolak (2011), Okay and Günöz (2009), Onursal and Gözlekçi (2007), and İkram et al. (2014) stated that GA_3 application at low concentrations was more effective in breaking dormancy

Potassium Nitrate. Potassium nitrate application had a significant effect on the total germination rate of *A. pseudalhagi*, while its effect on normal germination and abnormal germination rate was not found to be significant. While the total germination rate was calculated as 24.0% in the application of KNO_3 with 2% concentration, it was determined that the total germination rate increased to 41% in the 4% application (Table 2). It was observed that the abnormal germination rate increased depending on the increase in KNO_3 concentration (Table 2).

When the literature studies were examined, no KNO_3 application was found in the seeds of *Alhagi* species in order to break dormancy. In studies conducted on different species, it is known that KNO_3 application on some species was effective in breaking dormancy (İkram et al., 2014), while it was not effective in some species (Zhou et al., 2012).

Cold Moist Stratification. Cold stratification application of *A. pseudalhagi* seeds was found to be statistically significant in total germination and normal germination rates. Total germination rates were 9.3% and 49.3%, and normal germination rates were 8.0% and 46.6%, respectively, in 3 and 4 weeks of cold stratification. Longer (4 weeks) cold stratification of seeds resulted in significant increases in total and normal germination rates of seeds. On the other hand, the cold stratification time did not cause a significant change in abnormal germination rates (Table 2). In this application, it was observed that *A. pseudalhagi* seeds, whose moisture and cooling needs were met, caused an increase in the germination rate of seeds by breaking dormancy.

Although cold stratification applications and dormancy removal applications in *A. pseudalhagi* seeds are not encountered in the literature, cold stratification application of *A. camelorum* species of *Alhagi* genus affects the germination rate of the seeds compared to the control and it is successful in removing dormancy (Esmaili & Esmaili, 2010); on the other hand, it has been shown that cold stratification applications are successful in breaking dormancy in different species (Hashim et al., 2018; Isavand et al., 2005; Jones et al., 2016; Kambur & Tilki, 2010; Onursal & Gözlekçi, 2007). The effect of cold stratification in breaking dormancy in the current study supports previous studies.

Warm Moist Stratification. Warm moist stratification of *A. pseudalhagi* seeds caused significant changes in total germination and normal germination rates. In 1 and 2 weeks of warm moist stratification, total germination rates were 14.7% and 44.0%, and normal germination rates were 12.0% and 38.6%, respectively, Longer (2 weeks) warm moist stratification of seeds resulted in significant increases in total and normal germination rates. On the other hand, the warm moist stratification time did not cause a significant change in abnormal germination rates (Table 2).

In the literature review, it was seen that warm moist stratification was not applied to *A. pseudalhagi* seeds. On the other hand, It has been determined that warm moist stratification applied to seeds causes a decrease in the germination rate of seeds of *Salsola kali* subsp. *ruthenica* (Obalı, 2009).

Warm + Cold Moist Stratification. It was seen that the effect of warm + cold moist stratification on the total and abnormal germination rate of *A. pseudalhagi* seeds was significant, but the effect on normal germination was insignificant. In 1 + 3, 1 + 4, 2 + 3, and 2 + 4 applications of warm + cold moist stratification, the total germination rates were 24.0%, 32.0%, 40.0%, and 26.7%, while the abnormal germination rates were 2.7%, 0.0%, 18.7%, and 2.7%, respectively. The highest abnormal germination rate was obtained in 2-week warm + 3-week cold stratification (Table 2).

In the literature review, it was seen that warm + cold moist stratification application was not applied to *A. pseudalhagi* seeds. On the other hand, 3-week warm stratification + 12-week cold stratification applied to *Fraxinus ornus* seeds caused an increase in the germination rate of seeds (Tilki, 2005), while warm + cold moist stratification application did not cause an increase in the germination rate of *Flueggea anatolica* seeds (Avşar & Ok 2009).

Cold + Warm Moist Stratification. While cold + warm moist stratification for different durations significantly affected the total and normal germination rates of *A. pseudalhagi* seeds, its effects on abnormal germination rates were insignificant. In the application of cold + warm stratification for 3 + 1, 3 + 2, 4 + 1, and 4 + 2 periods, the total germination rates were determined as 32.0%, 25.3%, 40.0%, and 33.3%, while the normal germination rates were determined as 25.3%, 16.6%, 28.0%, and 24.0%, respectively (Table 2).

Cold Water. While significant changes were observed in the total and normal germination rates of *A. pseudalhagi* seeds kept in cold water for 1, 2, and 4 weeks, the changes were insignificant in abnormal germination rates. The seeds kept in cold water for 2 weeks obtained the highest total and normal germination rates of 41.3% and 36.0%, respectively. Soaking the seeds in cold water for a longer time resulted in a decrease in total and normal germination rates (Table 2). It was determined that keeping the seeds in cold water for 2 weeks was sufficient to meet the chilling needs of the *A. pseudalhagi* seeds and to break the physiological dormancy while keeping them in cold water for a longer time reduced the germination of the seed.

In the literature review, it was seen that no cold water soaking was applied to the seeds of *A. pseudalhagi*. It was determined that the seeds of other plant species, *Astragalus adscendens* and *Astragalus podolobus*, kept in cold water (10 days at 4°C) caused an increase in germination rate (Tavili et al., 2014), while in another study, it did not cause an increase in the germination rate of *Salsola kali* subsp. *ruthenica* (Obalı, 2009).

Hot Water. Significant changes were observed in total, normal, and abnormal germination rates of *A. pseudalhagi* seeds, which were soaked in boiling water for different times (2 and 4 minutes). When the seeds of *A. pseudalhagi* were soaked in hot water for 2 and 4 minutes, the total germination rates were 58.7% and 24.0%, the normal germination rate was 36.0% and 9.3%, and the abnormal germination rates were 22.6% and 14.7%, respectively.

Soaking in hot water for a long time (4 minutes) caused a decrease in the germination rate of *A. pseudalhagi* seeds (Table 2).

It has been observed that soaking in boiling water for 2 minutes is sufficient to obtain high germination rates. It is estimated that hot water application has a significant effect on the permeability of the seed coat and contributes to the increase in germination rate. On the other hand, it can be said that keeping the seeds in hot water for a long time causes damage to the embryos of seeds. When the researchers were examined, while soaking in hot water was found in many genus and species, hot water soaking was not applied in the *A. pseudalhagi* species. In studies on other *Alhagi* species, it has been determined that soaking in hot water affects the breaking of dormancy of seeds and increases the germination rate (Anosheh, 2020; Esmaili & Esmaili, 2010; Mohammad et al., 2010).

In other plant genus and species, soaking in hot water has been widely practiced. Accordingly, soaking of seeds of *Astragalus maritimus*, *Astragalus verrucosus*, *A. adscendens*, *A. podolobus*, *Astragalus hamosus*, *Astragalus cyclophyllon*, and *Astragalus arpilobus* in hot water increased the germination rate of the seeds (Bacchetta et al., 2011; Keshtkar et al., 2008; Long et al., 2012; Patane and Gresta 2006; Tavili et al., 2014). On the other hand, it was determined that soaking in hot water did not increase the germination rate of *Astragalus gines-lopezii*, *Astragalus filipes*, and *Astragalus cicer* seeds, and it was not an effective method for breaking dormancy (Kildisheva et al., 2018; Schnadelbach et al., 2016; Statwick, 2016).

Mechanical Scarification. Application of mechanical scarification for 5, 10, and 15 minutes significantly affected the total and abnormal germination rates of *A. pseudalhagi* seeds, while the effect on normal germination rate was insignificant. The application of mechanical scarification for 5, 10, and 15 minutes showed that the total germination rates of *A. pseudalhagi* seeds were 33.3%, 36.0%, and 52.0%, while abnormal germination rates were 2.7%, 9.3%, and 13.3%, respectively, Increases in total, normal, and abnormal germination rates were observed depending on the increase in mechanical scarification application time (Table 2). It has been observed that the long-term mechanical scarification application causes damage to the embryos of the seeds and causes an increase in the abnormal germination rate. Therefore, mechanical scarification for longer than 15 minutes is predicted to increase abnormal germination in *A. pseudalhagi* seeds.

In previous studies, it was determined that the application of mechanical scarification to *A. pseudalhagi*, *A. cancencens*, *A. kirghisorum*, *A. camelorum*, *A. sparsifolia*, and *A. maurorum* seeds increased the germination rate of the seeds (Anosheh, 2020; Esmaili & Esmaili, 2010; Karshibaev, 2014).

Chemical Scarification. Application of sulfuric acid to *A. pseudalhagi* seeds for 10, 20, and 30 seconds did not cause any significant change in total, normal, and abnormal germination rates. In the application of soaking in sulfuric acid for 10, 20, and 30 seconds, the total germination rate was 36.0%, 32.0%, and 37.3%, the normal germination rate was 24.0%, 25.3% and 28.0%, and the abnormal germination rates were 12.0%, 6.7%, and 9.3%, respectively (Table 2).

The seeds of many *Alhagi* genus were treated with sulfuric acid as a chemical scarification. They determined that sulfuric acid applied to *A. pseudalhagi*, *A. cancencens*, *A. kirghisorum*, *A. sparsifolia*, and *A. maurorum* seeds was very effective in breaking dormancy (Kerr et al., 1965; Esmaili & Esmaili, 2010; Mohammad et al., 2010; Karshibaev, 2014; Anosheh, 2020).

Comparison of Dormancy-Breaking Treatments

The highest total germination values in each dormancy-breaking application were compared with the control (25/15°C) application without any dormancy-breaking application. Seed germination rates of *A. pseudalhagi* in different dormancy-breaking applications are given in Table 3.

It was determined that the effect of dormancy-breaking application on the total, normal, and abnormal germination rates of *A. pseudalhagi* was different. The highest total germination

Table 3.
Comparison of Different Dormancy-Breaking Treatments on Seed Germination of Alhagi pseudalhagi

Applications	Total Germination (%)	Normal Germination (%)	Abnormal Germination (%)
Control	33.3 e	28.0 cd	5.3 de
Matrix-priming (48 hours)	37.3 e	32.0 cd	5.3 de
Hydro-priming (48 hours)	44.0 cde	34.7 c	9.3 cd
Gibberellic acid (250 ppm)	61.3 a	50.7 a	10.7 cd
Potassium nitrate (4%)	41.3 cde	28.0 cd	13.3 bc
Cold moist stratification (4 weeks)	49.3 bcd	46.7 ab	2.7 e
Warm moist stratification (2 weeks)	44.0 cde	38.7 d	5.3 de
Warm + cold moist stratification (2 weeks + 3 weeks)	40.0 de	21.3 d	18.7 ab
Cold + warm moist stratification (4 weeks + 1 week)	40.0 de	28.0 cd	12.0 c
Cold water (2 weeks)	41.3 cde	36.0 bc	5.3 de
Hot water (2 minutes)	58.7 ab	36.0 bc	22.7 a
Mechanical scarification (15 seconds)	52.0 abc	38.7 bc	13.3 bc
Chemical scarification (30 seconds)	37.3 e	32.0 cd	5.3 de
LSDs	11.0**	11.7**	6.3**

Note: LSD = Least significance difference; ns = Not significant.
**$p < .01$ significant within probability limits.

rates were obtained in GA_3 at 61.3%, soaking in hot water at 58.7%, and mechanical scarification at 52.0%, respectively. Compared to the control, GA_3 increased the total germination rate by 28.0%, hot water by 25.4%, mechanical scarification by 18.7%, and cold moist stratification by 16.0%. Although other dormancy-breaking treatments slightly increased the total germination rate, these increases were found to be statistically insignificant. Normal germination rate was obtained with 50.7% GA_3 and 46.7% cold stratification application. Gibberellic acid increased the normal germination rate by 22.7% and cold stratification by 18.7% compared to the control. It was observed that other dormancy-breaking treatments did not significantly affect the normal germination rate compared to the control treatment. The highest abnormal germination rates were obtained with 22.7% in hot water soaking and 18.7% in warm + cold moist stratification applications.

There are a number of dormancy types that prolong or inhibit the germination process in seeds. Partial dormancy type causes gradual germination, and this slow germination negatively affects seedling quality and inhibits the growth of an exemplary plant (Demir et al., 2008). A number of methods such as cold stratification, hormonal applications, light, mechanical and chemical scarification, and variable temperatures are used to remove dormancy in seed technology, but their effects differ from species to species (Baskin & Baskin, 2004; Ozden et al., 2021; Roberts & Benjamin, 1979; Stout, 1998). It seems that partial dormancy in the *A. pseudalhagi* species can be eliminated at different rates with some dormancy-breaking applications.

Sulfuric acid, mechanical scarification, HP, soaking in hot water, KNO_3 application, and cold stratification were applied in order to break dormancy in the seeds of *Alhagi* species (Anosheh, 2020; Esmaili & Esmaili, 2010; Karshibaev, 2014; Kerr et al., 1965; Mohammad et al., 2010). However, GA_3 application was not found in the seeds of *Alhagi* species. In our current study, it was determined that the most effective method in breaking dormancy was the application of GA_3.

In the present study, the highest seed germination rate was determined at 25/15°C, while germination was not found at 10°C. Relative to the control treatment, GA_3, hot water, and mechanical scarification contributed significantly to the breaking of dormancy in *A. pseudalhagi* seeds, while the effects of other dormancy-breaking treatments were insignificant. According to the present results, it was determined that GA_3 28.0%, hot water 25.4%, and mechanical scarification 18.7% removed dormancy. As a result, considering that it is easy to apply in practice, it has been observed that dormancy can be significantly broken with hot water without using any chemicals (hormones).

When the seeds of the *A. pseudodalhagi* plant will be used in the evaluation of arid, saline, and erosion areas, germination rates will increase if they are sown after being kept in boiling hot water at 100°C for 2 minutes.

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