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Seed Dormancy Dynamics and Germination Characteristics of *Malva parviflora* L.

Rakesh Dawar [1], Vishwanath Rohidas Yalamalle [2,*], Ram Swaroop Bana [1,*], Ramanjit Kaur [1], Yashbir Singh Shivay [1], Anil K. Choudhary [1,3], Teekam Singh [1], Samrath Lal Meena [1], Dunna Vijay [2], H. P. Vijayakumar [2], Vipin Kumar [1,4] and Achchhelal Yadav [5]

[1] Division of Agronomy, ICAR—Indian Agricultural Research Institute, New Delhi 110012, India
[2] Division of Seed Science and Technology, ICAR—Indian Agricultural Research Institute, New Delhi 110012, India
[3] Division of Crop Production, ICAR—Central Potato Research Institute, Shimla 171001, India
[4] Department of Agronomy and Horticulture, University of Nebraska—Lincoln, Lincoln, NE 68583-0915, USA
[5] Division of Agricultural Physics, ICAR—Indian Agricultural Research Institute, New Delhi 110012, India
* Correspondence: vishwanath_yal@yahoo.com (V.R.Y.); rsbana@gmail.com (R.S.B.)

Abstract: Little mallow (*Malva parviflora* L.) is a notorious weed that causes substantial yield losses in winter crops. For effective weed management and seed testing, a deeper understanding of seed dormancy, germination behavior, and dormancy-breaking methods is necessary. Experiments were conducted to determine the effect of seed treatments, i.e., mechanical scarification, acid scarification, hot water treatment, and different germinating temperatures, i.e., 15 °C, 20 °C, or alternating 15–20 °C (16/8 h), on the seed dormancy in *M.parviflora*. A large proportion of *M. parviflora* seeds were physically dormant, with just 10.90% germination. Seed treatments had a significant influence on seed germination, seedling dry weight, vigor index, and water absorption ($p \leq 0.01$). Among the various treatments, mechanical scarification enhanced germination by 32%, the vigor index by 487% and water uptake by 34%, and decreased percent hard seeds by 34%. Among the various germination temperatures, alternating 15–20 °C temperatures (16/8 h) gave the most significant result for germination and the lowest percent hard seeds. The findings of this study will serve as a valuable reference for seed testing and the development of suitable weed control strategies for *M. parviflora*.

Keywords: dormancy; germination; malva parviflora; scarification; acid treatment; weed biology

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1. Introduction

Malva parviflora L. is a member of the Malvaceae family, which includes at least 243 genera and about 4225 species [1]. It is a popular annual or perennial herb with a decumbent or erect habit and is widely naturalized across Africa, Asia, and Europe. This species is a notorious weed in winter crops like wheat, causing substantial yield losses [2]. *M. parviflora* is also a medicinal plant reported to have diverse therapeutic potential, including antibacterial, antidiabetic, antifungal, hepatoprotective, neuroprotective, anti-irritant, antioxidant, anti-ulcerogenic, and analgesic properties [3].

Seed dormancy, a well-known adaptive mechanism that ensures the survival of plants by delaying germination until environmental conditions are favorable, is very common in the Malvaceae family [4]. Among the principal reasons for dormancy, seed-coat-imposed physical dormancy is most common in *M. parviflora* [5]. It is mainly caused by hydrophobic substances, like lignin and wax, which lead to hardness and impermeability to water and oxygen, and consequently result in low germination in several Malvaceae species [6–8]. Apart from the seed-coat-imposed physical dormancy, some members of Malvaceae can be non-dormant or have a combination of physiological and physical dormancy [9,10]. Several techniques have been developed to break seed-coat-imposed dormancy. These techniques

include mechanical scarification, acid scarification, hot water, enzymes, high atmospheric pressures, dry heat, and high temperatures [11].

Mechanical scarification involves creating a scar on the seed coat with a scalpel or sandpaper. This technique is effective in many species with physical dormancy, including *M. parviflora*. [12]. One of the advantages of mechanical scarification is that there is minimal damage to the seeds compared to acid and hot water treatments [13]. Mechanical scarification can be laborious, but special machines are available that can automate the process [14].

Likewise, sulfuric acid (H_2SO_4) can also be used to enhance seed coat permeability, which is beneficial in promoting seed germination in cases of physical dormancy or hard seed coatedness. However, prolonged exposure to H_2SO_4 can damage seeds, increase seed mortality, and lead to the development of abnormal seedlings [13]. Scarification with H_2SO_4 was identified as the most effective method for breaking seed dormancy in freshly harvested seeds of *Malva sylvestris* [15].

Additionally, hot water treatment is frequently used to overcome dormancy in seeds with hard seed coats. Usually, seeds are soaked in hot water at temperatures ranging from 40 to 100 °C for a specific duration, depending on the species and the thickness of the seed coat [16]. Hot water treatment softens the hard seed coat, enabling the entry of water and air into the seed. The effectiveness of hot water in breaking seed dormancy varies from species to species [17,18]. Wang et al. [14] reported that soaking wild Vigna species seeds for 3 to 6 min in 80 °C water was effective in breaking the seed coat dormancy. Tadros et al. [16] observed that soaking *Leucaena leucocephala* (Lam.) seeds in 70 °C water for 20 min was effective in breaking seed dormancy.

In the current study, we investigated the effect of various physical and chemical pretreatments, as well as different temperature regimes, on dormancy, seed vigor, and water uptake patterns in the seeds of *M. parviflora*. Information on the nature and the conditions that alleviate seed dormancy in *M. parviflora* seeds is limited. Unlike previous studies in *M. parviflora*, we used freshly harvested seeds for seed dormancy studies. It is well known that storage often reduces dormancy in many species [19]. Furthermore, there are limited reports on the optimal temperature for breaking dormancy in *M. parviflora*. Apart from being a weed, *M. parviflora* has medical value. For the conservation of *M. parviflora* germplasm, the protocol for seed dormancy breaking is not given in the International Seed Testing Association [20] guidelines, which are followed by several gene banks, including those in India [21]. Our study findings will help in seed testing and conservation and designing effective weed control strategies to control *M. parviflora* infestation in field crops.

2. Materials and Methods

2.1. Seeds Source

Seeds of *M. parviflora* were harvested in May 2022 from 15 to 20 mature plants growing in wheat fields on the Research Farm of ICAR-IARI, New Delhi, situated at latitude 28°4′ N, longitude 77°12′ E, and 228.6 m altitude. Around 100 capsules were harvested from different plants (Figure 1a). These were dried in the sun for two days. The seeds were separated manually from each capsule. The seeds obtained were mixed to form one composite sample (Figure 1b,c). Seeds were immediately used for dormancy studies (Table 1).

Table 1. Physical characteristics of mellow seeds.

	1000-Seed Weight (g)	Length (mm)	Width (mm)	Length-to-Width Ratio
Average	0.83 ± 0.02	0.156 ± 0.014	0.138 ± 0.016	1.144 ± 0.168
Range	0.73	0.064	0.072	0.80

The average value is expressed as the means ± standard deviation (n = 100).

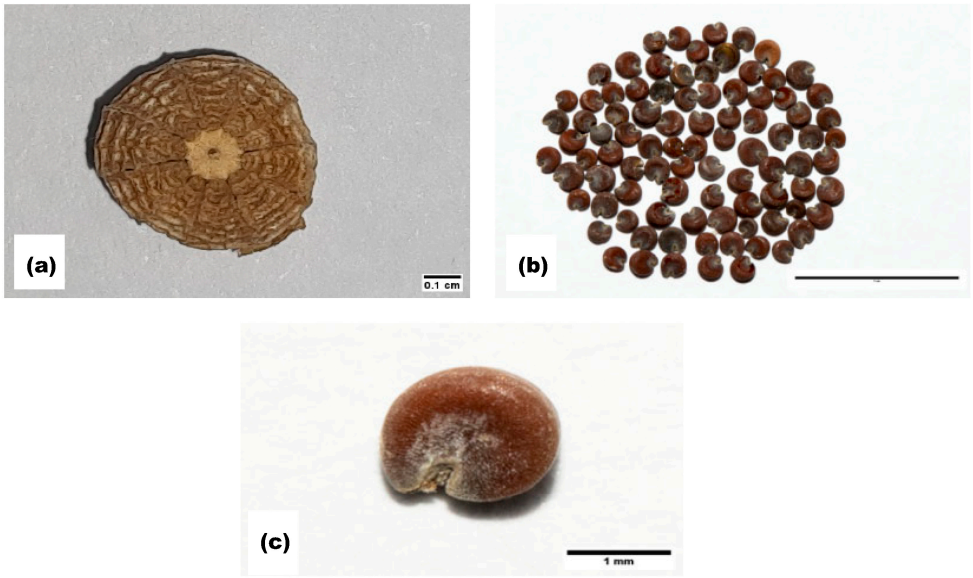

Figure 1. (**a**) Little mallow (*Malva parviflora* L.) seed capsule, scale bar = 0.1 cm; (**b**) seeds of little mallow, scale bar = 1 cm; (**c**) magnified image of a single seed, scale bar = 0.1 cm.

2.2. Seed-Dormancy-Breaking Treatments

The freshly harvested seeds of *M. parviflora* were subjected to various dormancy-breaking treatments (Table 2). Mechanical scarification was carried out using sandpaper. Seeds were gently abraded between two sheets of fine sandpaper in an area opposite the embryo until the cotyledon was exposed.

Table 2. Treatment details.

Treatments	Note
Mechanical scarification	# 80 wood sandpaper
Acid treatment 5 min	95% sulfuric acid (H_2SO_4)
Acid treatment 10 min	
Acid treatment 15 min	
Hot water treatment for 30 min	Seeds immersed in distilled water at 80 °C
Hot water treatment 60 min	
Intact seed	

Acid scarification was performed as previously described by Botsheleng et al. [22]. From the seed lot, three batches of 150 seeds each were counted. The seeds were then put into three 100 mL heat-resistant, non-corrosive glass beakers, and concentrated sulfuric acid (95%) was slowly added into the beakers to a level where all seeds were covered (about 50 mL). The seeds were treated for 5, 10, and 15 min with constant stirring at regular intervals to ensure equal exposure. After each soaking period, the sulfuric acid was drained off, and the seeds were repeatedly rinsed in running tap water until they were considered safe to handle. After treatment, the seeds were thoroughly washed with running water. In the same manner, for the hot water treatment, 300 seeds were counted from the seed lot and then divided into batches of 150 seeds. The seeds were then put into three 100 mL heat-resistant glass beakers, and 100 mL of distilled water was added. The glass beaker was immersed in a hot water bath set at 80 °C for 30 or 60 min.

2.3. Seed Germination Procedure

After treatment (Table 2), seeds were subjected to a germination test with replicates (n = 3). Fifty seeds were placed in plastic Petri plates (diameter 11 cm) containing two Whatman No. 1 filter papers. Filter papers were moistened with 10 mL of distilled water. These Petri plates were incubated at 15 °C, 15–20 °C (16/8 h), and 20 °C. The seeds were considered germinated when the radicle was 1 mm or longer. The number of normal seedlings, hard seeds, and dead seeds was recorded after 21 days.

2.4. Water Uptake Studies

Water imbibition experiments were performed on both scarified and non-scarified seeds. The acid-scarified seeds were washed in running water to remove any trace of acid and then dried at room temperature (25 ± 2 °C) for 48 h before being tested for water imbibition. To determine water uptake capacity during seed imbibition, three sets of 50 scarified and non-scarified seeds were weighed using an analytical balance with an accuracy of 0.01 mg and then placed in Petri dishes on two discs of filter paper moistened with 10 mL of distilled water at room temperature (25 ± 2 °C). After each imbibition period (from 0 to 8 h), seeds were surface-dried with filter paper, reweighed, and returned to the Petri dish. The percentage of water uptake (mean value ± standard error) was calculated as the amount of water taken up relative to the initial seed mass.

2.5. Hard Seeds

At the end of the germination test, i.e., 21 days, the seeds that remained ungerminated, firm, and had not absorbed water were categorized as hard seeds.

2.6. Determination of 1000-Seed Weight

Eight replicates of 100 seeds were weighed and used to calculate the mean 1000-seed weight as per [20]. The average moisture content of seeds was 7.2% at the time of the 1000-seed weight determination.

2.7. Determination of Seed Physical Characteristics

The seed physical characteristics, i.e., length and breadth, were measured digitally using Image J software version 1.54 b (https://imagej.nih.gov/ij/index.html (accessed on 11 May 2023). Seed length and seed width were calculated based on the average of 100 randomly selected seeds. The length-to-width ratio was calculated by dividing the length and width.

2.8. Seed Vigor Indices

Seed vigor was calculated as per Abdul-baki and Anderson, 1973 [23]. On the 21st day, ten normal seedlings were chosen randomly. The seedlings were then dried at 50 °C ± 1 until they reached a constant weight. The seedling vigor index was calculated by multiplying the percentage of germination with the average weight of the ten selected seedlings, measured in milligrams.

2.9. Tetrazolium Staining (TZ)

The TZ test was conducted twice, before and after seed treatment. The initial TZ test was carried out to assess the percentage of viable seeds in the seed lot. In the post-treatment TZ test, only the seeds that did not germinate were examined to assess whether the seed treatments resulted in seed mortality. For the initial TZ test, ten seeds per treatment were longitudinally cut through the fruit and seed coat, followed by the removal of the seed coat and endosperm to expose the embryo. The embryos were soaked in a 1% 2, 3, 5-triphenyl tetrazolium chloride solution at 30 °C in the dark for 18 h. After the staining period, the seeds were washed with water and assessed based on the intensity and consistency of tissue color. The seeds were then categorized as viable or non-viable based on the staining pattern in vital parts of the embryo [24].

2.10. Statistical Analysis

Experiments were conducted using a completely randomized design. Each Petri plate containing 50 seeds was considered as a single unit. Experimental data were recorded, and averages were plotted using GRAPES software Version 1.0.0 developed by Kerala Agriculture University [25]. The effect of seed treatment and temperature regime on germination %, seedling dry weight, seed vigor index, and water uptake were investigated using ANOVA. The mean comparisons of all experiments were calculated based on Tukey's (honestly significant difference) at the 0.05 level of probability.

3. Results

3.1. Effect of Seed Treatments on Germination Percent

Data on the germination of *M. parviflora* as influenced by seed treatment and temperature are presented in Table 3 and Figures 2 and 3. The initial seed viability of the seeds was assessed using the TZ test based on the staining pattern of the seeds in the vital parts as per ISTA guidelines, 2003. The germination potential of the seeds was found to be 70%. Among different seed treatments, the highest rate of germination (43.78%) was found in seeds subjected to mechanical scarification. Conversely, no germination was recorded after a 60 min hot water treatment (Figure 3). The temperature had a significant ($p \leq 0.01$) effect on germination. The highest rate of germination (26.19%) was found at 15–20 °C. The lowest rate of germination (17.05%) was observed at 20 °C. The interaction effect of seed treatment and germination temperature was significant ($p \leq 0.01$). The highest rate of germination (58.67%) was found with a combination of mechanical scarification and 15–20 °C temperature, which was statistically similar to the combination of mechanical scarification and 15 °C temperature and a combination of 15 min acid treatment and 20 °C temperature.

Table 3. Effect of different dormancy-breaking treatments on the germination of little mallow (*Malva parviflora* L.) seeds.

Treatments	**Germination (%)**			
	15 °C	**15–20 °C**	**20 °C**	**Mean Treatments**
Mechanical scarification	40.67 (39.52) ab [#]	58.67 (50.01) a	32.00 (34.40) bc	**43.78 (41.31) A**
Acid 5 min	23.33 (28.83) cde	28.67 (32.35) bcd	21.33 (27.44) cde	**24.44 (29.54) B**
Acid 10 min	27.33 (31.51) bcd	37.33 (37.63) bc	22.67 (28.29) cde	**29.11 (32.48) B**
Acid 15 min	30.67 (33.58) bc	44.67 (41.93) ab	37.33 (37.65) bc	**37.56 (37.72) A**
HW 30 min	0.00 (0.02) h	1.33 (3.86) gh	0.00 (0.02) h	**0.44 (1.30) F**
HW 60 min	0.00 (0.02) h	0.00 (0.02) h	0.00 (0.02) h	**0.00 (0.02) F**
Intact seed	14.00 (21.94) def	12.67 (20.48) ef	6.00 (13.84) fg	**10.89 (18.75) E**
Mean temperature	**19.43 (22.20) B**	**26.19 (26.61) A**	**17.05 (20.24) B**	
Factor				
Factor A (Seed treatment)	4.49 ***			
Factor B (Temperature)	2.94 ***			
Factor (A × B)	7.78 **			

[#] Different letters indicate significant differences between treatments at $p < 0.05$; capital letters are used for the main effect and small letters for interaction between treatments and germination temperature. Significance codes: *** $p < 0.001$; ** $p < 0.01$. The values in the parenthesis are arcsine-transformed values.

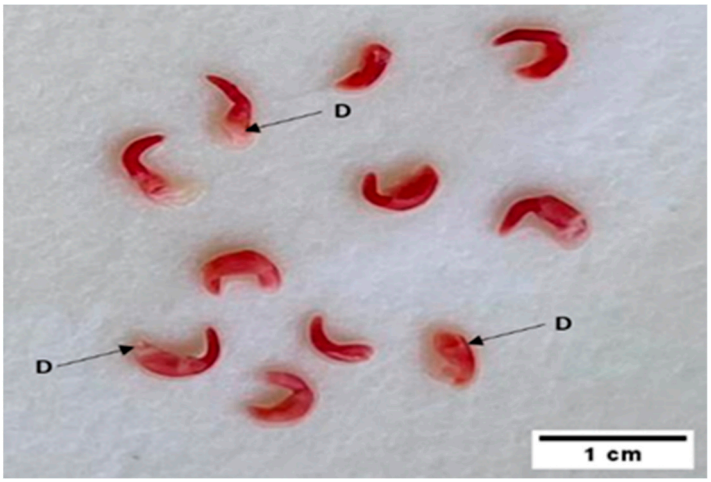

Figure 2. 2, 3, 5-triphenyl tetrazolium chloride-stained seeds of little mallow (*Malva parviflora* L.) in the control group depicting viable (unmarked) and (D) non-viable seeds as per ISTA (2003). Scale bar = 1 cm.

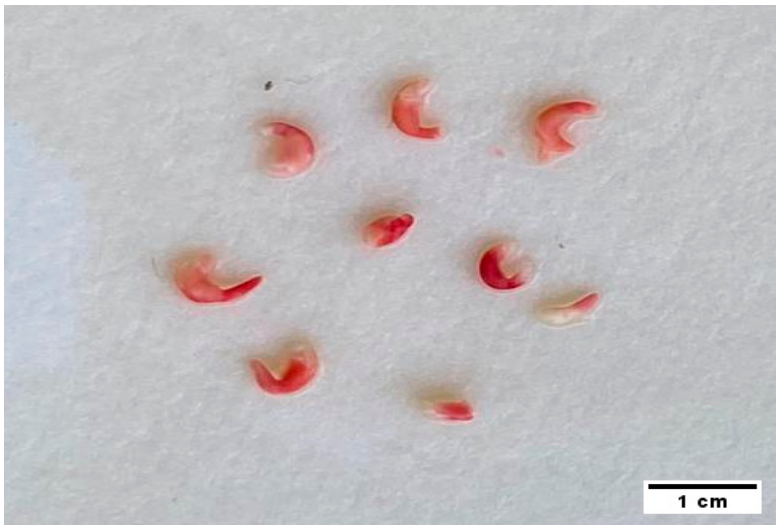

Figure 3. 2, 3, 5-triphenyl tetrazolium chloride-stained seeds of little mallow (*Malva parviflora* L.) depicting non-viable seeds after 60 min hot water treatment as per ISTA (2003). Scale bar = 1 cm.

3.2. Effect of Seed Treatments on Seedling Dry Weight

The seedling dry weight (SDW) after seed treatments is presented in Table 4. The seed treatment had a significant ($p \leq 0.01$) effect on SDW. The highest SDW (0.34 g) was observed in 10 min acid scarification; however, no statistically significant difference in the SDW was observed among the acid treatment and mechanical scarification. No seedling dry weight was recorded due to the absence of germination for both the 30 min hot water treatment at 15 and 20 °C, as well as the 60 min hot water treatment. The temperature had no significant effect on SDW. The interaction effect of seed treatment and germination temperature remained non-significant.

3.3. Effect of Seed Treatments on Vigor Index

The seed treatments had a significant ($p \leq 0.01$) effect on the vigor index (Table 4). Among the different treatments, mechanical scarification recorded a significantly higher vigor index (14.74), which was statistically similar to the 15 min acid treatment. No vigor index was recorded due to the absence of germination for both the 30 min hot water treatment at 15 °C and 20 °C, as well as the 60 min hot water treatment. The interaction

effect of seed treatment and germination temperature was significant ($p \leq 0.05$). The highest vigor index (20.6) was found with a combination of mechanical scarification and a 15–20 °C temperature, which was statistically similar to the combination of mechanical scarification and a 15 °C temperature and a combination of 15 min acid treatment and a 20 °C temperature.

Table 4. Effect of different dormancy-breaking treatments on the seedling dry weight and seed vigor index of little mallow (*Malva parviflora* L.) seeds.

Treatment	Seedling Dry Weight (g)				Seed Vigor Index			
	15 °C	15–20 °C	20 °C	Mean Treatments	15 °C	15–20 °C	20 °C	Mean Treatments
Mechanical scarification	0.34 #	0.35	0.31	**0.33 A**	13.82 ab	20.60 a	9.79 bc	**14.74 A**
Acid 5 min	0.34	0.23	0.31	**0.29 A**	7.76 bcde	6.81 bcde	6.70 bcde	**7.09 B**
Acid 10 min	0.36	0.35	0.32	**0.34 A**	9.72 bcd	13.24 ab	7.54 bcde	**10.17 B**
Acid 15 min	0.36	0.24	0.34	**0.31 A**	10.99 b	10.24 bc	12.54 ab	**11.26 AB**
HW 30 min	NA	0.07	NA	**0.02 B**	NA	0.26	NA	**0.09 C**
HW 60 min	NA	NA	NA	**0.00 B**	NA	NA	NA	**0.00 C**
Intact seed	0.36	0.21	0.17	**0.24 A**	4.98 bcde	1.87 cde	0.67 de	**2.51 C**
Mean temperature	**0.25 A**	**0.21 A**	**0.21 A**		**6.75 A**	**7.57 A**	**5.32 A**	
Factor								
Factor A (Seed treatment)	0.08 ***				2.74 ***			
Factor B (Temperature)	NS				NS			
Factor (A × B)	NS				4.80 **			

Different letters indicate significant differences between treatments at $p < 0.05$; capital letters for the main effect and small letters for interaction between treatments and germination temperature. Significance codes: *** $p < 0.001$; ** $p < 0.01$; NS, non-significant. NA, not available due to no germination.

3.4. Effect of Seed Treatment on Water Absorption %

The imbibition pattern showed an increase in mass with time, which was higher in scarified seeds than in non-scarified seeds (Figure 4). Seed treatment had a significant effect on the percent water absorption of seeds ($p \leq 0.01$). Among the different treatments, mechanical scarification recorded a significant percent water uptake (48.29%), and the lowest water uptake was recorded in intact seeds (15.32%). The germination temperature and the interaction effect were non-significant.

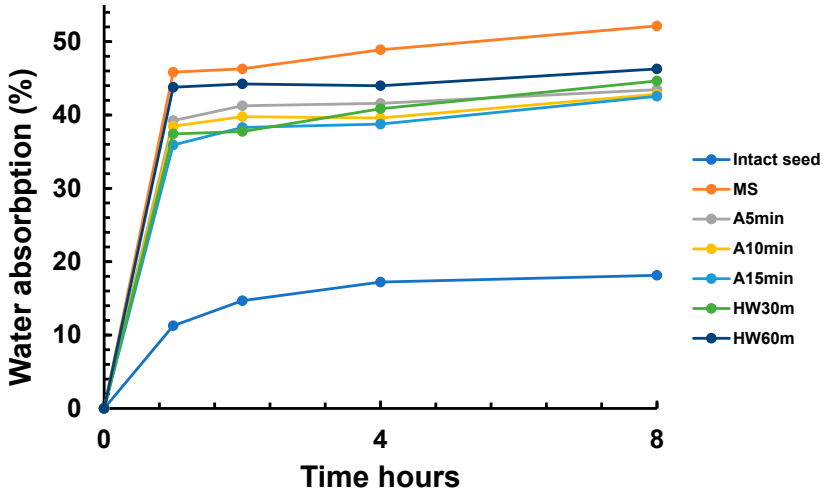

Figure 4. Time course for an increase in seed mass in little mallow (*Malva parviflora* L.) due to water absorption at ambient laboratory conditions (25 ± 2 °C). MS—mechanical scarification; A5Min—H_2SO_4 treatment for 5 min; A10 min—H_2SO_4 treatment for 10 min; A15 min—H_2SO_4 treatment for 15 min; HW30—hot water treatment for 30 min; HW60—hot water treatment for 60 min.

3.5. Effect of Seed Treatments on Hard Seeds

The seed treatments had a significant ($p \leq 0.01$) effect on percent hard seeds (Table 5). Among the different seed treatments, the lowest percent of hard seeds was recorded in the mechanical scarification (23.56%), which was statistically similar to the 10 min acid treatment, 15 min acid treatment, and hot water treatment for 30 and 60 min. The highest percent hard seeds was recorded in the control (57.56%), which was statistically similar to the 5 min acid treatment. The germination temperature and the interaction effect were non-significant.

Table 5. Effect of different seed-dormancy-breaking treatments on percent hard seeds in little mallow (*Malva parviflora* L.).

Treatments	**Percent Hard Seeds**			
	15 °C	**15–20 °C**	**20 °C**	**Mean Treatments**
Mechanical scarification	28.00 (31.79) abcd [#]	12.00 (20.15) d	30.67 (33.55) abcd	**23.56 (28.50) C**
Acid 5 min	40.00 (39.32) abcd	48.66 (44.23) abc	44.00 (41.51) abcd	**44.22 (41.66) AB**
Acid 10 min	54.00 (47.67) abc	32.67 (34.68) abcd	30.67 (33.44) abcd	**39.11 (38.49) BC**
Acid 15 min	40.67 (39.32) abcd	21.33 (27.41) cd	22.67 (28.30) bcd	**28.22 (31.68) BC**
HW 30 min	29.33 (32.72) abcd	35.33 (36.40) abcd	38.00 (37.99) abcd	**34.22 (35.71) BC**
HW 60 min	24.67 (29.58) abcd	35.33 (36.46) abcd	32.00 (34.37) abcd	**30.67 (33.47) BC**
Intact seed	58.00 (49.60) ab	54.67 (48.56) abc	60.00 (50.94) a	**57.56 (49.70) A**
Mean temperature	**39.24 (38.52) A**	**34.28 (37.16) A**	**36.86 35.41) A**	
Factor				
Factor A (Seed treatment)	6.58 ***			
Factor B (Temperature)	NS			
Factor (A × B)	NS			

[#] Different letters indicate significant differences between treatments at $p < 0.05$; capital letters for the main effect and small letters for interaction between treatments and germination temperature. Significance codes: *** $p < 0.001$; NS, non-significant. The values in the parenthesis are arcsine-transformed values.

4. Discussion

Physical dormancy occurs in 15 families of angiosperms, 14 of which are eudicots and 1 a commelinids monocot [26]. Once physical dormancy is broken, seeds either germinate or rot [11], unless physiological dormancy is also present (combinational dormancy). Successful dormancy-breaking treatment must provide significant improvement in germination over the initial germination potential of a seed lot. The germination potential can be assessed by observing the staining pattern in the vital parts of the seed. Though the seeds were freshly harvested, the TZ test showed that the germination potential of the seed lot used in the present study was 70% (Figure 2). Several previous studies on *M. parviflora* have shown a germination rate of more than 90% [10]. The discrepancy may be due to the ecotype and climatic conditions the mother plant experienced at the time of harvest [27].

Previous studies have shown that the seeds of the Malvaceae family are non-dormant, physically dormant, or have a combinational dormancy of physical and physiological dormancy [9,10]. This suggests that a combination of different scarification treatments and temperatures can effectively break the dormancy in *M. parviflora*. Freshly harvested seeds of *M. parviflora* were treated with different scarification treatments along with different germination temperatures, which can effectively break the seed dormancy. The results reveal that seeds of little mallow are unlikely to germinate in the field unless scarified. The ecological role of seed dormancy is not just to prevent seed germination under unfavorable conditions but also to prevent the germination of seeds if the probability of survival is low [28,29]. In the present study, in the control group, 10.89% of seeds germinated. The results are also in agreement with previous studies in *M. parviflora*, *Malva neglecta*, and *Malva sylvestris*, where untreated seeds had 2–5% germination [12,30]. Seeds of round-leaved mallow and little mallow were impermeable to water, exhibiting low germination unless they underwent scarification [30,31]

Several methods are used to break the hard seed coat and increase the permeability of the seed coat, including mechanical (sandpaper) and chemical (acid) scarification and seed soaking in hot water [13,14,17]. Mechanical scarification (sandpaper) and chemical scarification (sulfuric acid for 5, 10, and 15 min) treatments gave a significantly ($p \leq 0.01$) higher germination percentage, seedling dry weight, and seed vigor index over the control. The highest germination percentage, seedling dry weight, and seed vigor index were found under mechanical scarification. This increase in germination due to scarification could be due to increased imbibition (Figure 4). Mechanical scarification cracks the hard seed coat, which is the barrier to water uptake and gas exchange and allows germination to proceed [32,33].

Acid treatment improved the germination linearly with the increase in the duration of exposure, and a maximum germination of 37.56% was recorded. The improvement in germination was low compared to mechanical scarification. Lower seed germination in acid scarification can be linked to damage caused by sulfuric acid to the embryo, seed coat, and food reserves [13]. Alternatively, the duration of exposure to acid may not be adequate. However, several studies have shown that exposure to sulfuric acid for longer durations may also damage the seeds, increase seed mortality, and result in the development of abnormal seedlings [34,35].

Hot water treatment did not significantly improve the germination; treatment resulted in the mortality of the seeds (Table 3, Figure 3). Hot water scarification techniques generally have a positive effect on the germination rate. Dada et al. [36] also reported that hot water treatment did not break dormancy in *M. parviflora*. Rincon et al. [37] reported that soaking the seeds in hot water induced seed germination; however, increasing the contact time of the seeds with hot water decreased the seed germination percentage. McDonnell et al. [18] treated Kankakee mallow seeds (Malvaceae) at 80 °C for 10–60 s. Exposure beyond 20 s led to a decline in seed germination. This indicates that *M. parviflora* seeds are susceptible to high temperatures; however, a detailed study is required to find the optimum temperature and duration for *M. parviflora* seeds. It may be concluded that the seeds of *M. parviflora* are more sensitive to wet heat treatment, which can lead to up to 100% seed mortality. This information will help in developing weed control strategies like soil solarization in *M. parviflora*, a difficult-to-control weed that is not susceptible to selective herbicides [38].

Once physical and physiological dormancy was released, *M. parviflora* seeds germinated over a wide range of temperatures, a common response of species with physical dormancy [11,39]. In comparison to 20 °C, higher germination was seen at lower temperatures, i.e., 15 °C, and the optimum temperature for germination was alternating temperatures of 15–20 °C (16/8 h) (Table 3). In India, *M. parviflora* is mainly associated with winter wheat. Which is sown in November, during which the average temperature ranges from 13 to 27 °C (Supplementary Materials, Table S1). The results are also in agreement with the study [10] on *M. parviflora* under Mediterranean conditions.

The absorption of water by seeds varied significantly due to treatments. Mechanical scarification led to the highest water absorption compared to acid scarification, hot water treatment, and the control treatment (Table 5), resulting in increased water uptake. This may have contributed to higher germination in mechanically scarified seeds. It has been reported previously that mechanical pretreatments directly scarify the seed testa and allow rapid water imbibition, whereas boiling water pretreatments are thought to primarily breach the strophiole, resulting in much slower water penetration [40]. These findings are supported by the results of [41] in *Malvella sherardiana*. They found that mechanical-scarification-treated seeds had greater uptake of water due to the scarification of the seed, which led to cracks in the hard seed coat that promoted the permeability of water and gases into the seed. Gupta et al. [42] also observed that scarified seeds absorbed more water in sunflower seeds compared to a control.

5. Conclusions

The present study confirms that mechanical and acid scarification stimulates germination in *M. parviflora*, indicating that the inhibition of germination in this species is primarily

due to the seed coat. Higher germination rates were observed at alternating temperatures of 15–20 °C (16/8 h), which correspond to the prevailing conditions during winter wheat sowing in Northern India. This suggests that this weed is well adapted to the winter cropping system of the Indo-Gangetic Plains, although further field experiments under diverse tillage and crop establishment systems and under varied agro-ecological conditions are necessary to test this hypothesis. The findings from our study will be valuable for the development of weed control strategies for winter-season crops like wheat, chickpea, mustard, and barley.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture14020266/s1, Table S1. Weekly meteorological data from May 2021 to April 2022 of the experimental farms from where the seeds were collected.

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References

1. Maity, S.K.; Patra, A.; Pal, B.; Malakar, A. Palyno-taxonomic study of some members of Malvaceae in Purba Medinipur, West Bengal, India. *Ann. Plant Sci.* **2018**, *7*, 2069–2072. [CrossRef]
2. Punia, S.; Singh, S.; Yadav, D.B.; Sindhu, V.; Duhan, A. Abundance, distribution and diversity of weeds in wheat in Haryana. *Indian J. Weed Sci.* **2017**, *49*, 187–190. [CrossRef]
3. Akbar, S.; Hanif, U.; Ali, J.; Ishtiaq, S. Pharmacognostic studies of stem, roots and leaves of *Malva parviflora* L. *Asian Pac. J. Trop. Biomed.* **2014**, *4*, 410–415. [CrossRef] [PubMed]
4. Willis, C.G.; Baskin, C.C.; Baskin, J.M.; Auld, J.R.; Venable, D.L.; Cavender-Bares, J.; Donohue, K.; de Casas, R.R.; The NESCent Germination Working Group. The evolution of seed dormancy: Environmental cues, evolutionary hubs, and diversification of the seed plants. *New Phytol.* **2014**, *203*, 300–309. [CrossRef]
5. Egley, G.H.; Paul Jr, R.N.; Duke, S.O.; Vaughn, K.C. Peroxidase involvement in lignification in water-impermeable seed coats of weedy leguminous and malvaceous species. *Plant Cell Environ.* **1985**, *8*, 253–260.
6. Corner, E.J.H. *The Seeds of Dicotyledons*; University Press: Cambridge, UK, 1976.
7. El Balla, M.M.A.; Saidahmed, A.I.; Makkawi, M. Effect of moisture content and maturity on hardseededness and germination in okra (*Abelmoschus esculentus* L. Moench). *Int. J. Plant Physiol. Biochem.* **2011**, *3*, 102–107.
8. Baskin, C.C.; Baskin, J.M. *Seeds Ecology, Biogeography, and Evolution of Dormancy and Germination*, 2nd ed.; Academic Press: San Diego, CA, USA, 2014.
9. Finch-Savage, W.E.; Leubner-Metzger, G. Seed dormancy and the control of germination. *New Phytol.* **2006**, *171*, 501–523. [CrossRef]
10. Michael, P.J.; Steadman, K.J.; Plummer, J.A. Climatic regulation of seed dormancy and emergence of diverse *Malva parviflora* populations from a Mediterranean-type environment. *Seed Sci. Res.* **2006**, *16*, 273–281. [CrossRef]
11. Baskin, C.C.; Baskin, J.M. *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*; Academic Press: San Diego, CA, USA, 1998.
12. Chauhan, B.S.; Gill, G.; Preston, C. Factors affecting seed germination of little mallow (*Malva parviflora*) in southern Australia. *Weed Sci.* **2006**, *54*, 1045–1050. [CrossRef]
13. Khalofah, A. The impact of different seed dormancy release treatments on seed germination of juniper (*Juniperus procera*). *J. King Saud Univ. Sci.* **2022**, *34*, 102307. [CrossRef]

14. Wang, Y.; Hanson, J.; Mariam, Y. Breaking hard seed dormancy in diverse accessions of five wild Vigna species by hot water and mechanical scarification. *Seed Sci. Technol.* **2011**, *39*, 12–20. [CrossRef]
15. Ansari, O.; Gherekhloo, J.; Kamkar, B.; Ghaderi-Far, F. Breaking seed dormancy and determining cardinal temperatures for Malva sylvestris using nonlinear regression. *Seed Sci. Technol.* **2016**, *44*, 447–460. [CrossRef]
16. Tadros, M.J.; Samarah, N.H.; Alqudah, A.M. Effect of different pre-sowing seed treatments on the germination of *Leucaena leucocephala* (Lam.) and *Acacia farnesiana* (L.). *New For.* **2011**, *42*, 397–407. [CrossRef]
17. Zare, S.; Tavili, A.; Darini, M.J. Effects of different treatments on seed germination and breaking seed dormancy of *Prosopis koelziana* and *Prosopis Juliflora*. *J. For. Res.* **2011**, *22*, 35–38. [CrossRef]
18. McDonnell, A.; Grant, M.; Coons, J.M. Effects of hot water on breaking seed dormancy of the endangered Kankakee mallow (*Iliamna remota* Greene (Malvaceae)). *Erigenia* **2012**, *25*, 8–13.
19. Geneve, R.L. Impact of tempreture on seed dormancy. *Hort. Sci.* **2003**, *3*, 38.
20. ISTA. *International Rules for Seed Testing*, 2021 ed.; International Seed Testing Association: Zurich, Switzerland, 2021.
21. Koul, A.K.; Jacob, S.R. Seed viability testing: Principles and practices. In *Training Manual International Training Programme on Management of Plant Genetic Resources for Officers from Directorate of Seed Testing and Certification*; Ministry of Agriculture: Baghdad, Iraq; NBPGR: New Delhi, India, 2019; pp. 57–64.
22. Botsheleng, B.; Mathowa, T.; Mojeremane, W. Effects of pre-treatments methods on the germination of Pod mahogany (*Afzelia quanzensis*) and mukusi (*Baikiaea plurijuga*) seeds. *Int. J. Innov. Res. Technol. Sci. Eng.* **2014**, *3*, 8108–8113.
23. Abdul-Baki, A.A.; Anderson, J.D. Vigor Determination in Soybean Seed by Multiple Criteria. *Crop. Sci.* **1973**, *13*, 630–633. [CrossRef]
24. ISTA. *International Rules for Seed Testing*, 2003 ed.; International Seed Testing Association: Zurich, Switzerland, 2003.
25. Gopinath, P.P.; Parsad, R.; Joseph, B.; Adarsh, V.S. GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics. 2020. Version 1.0.0. Available online: https://www.kaugrapes.com/home (accessed on 16 August 2023).
26. Baskin, J.M.; Baskin, C.C. Evolutionary considerations of claims for physical dormancy-break by microbial action and abrasion by soil particles. *Seed Sci. Res.* **2000**, *10*, 409–413. [CrossRef]
27. Royo-Esnal, A.; Onofri, A.; Taab, A.; Loddo, D.; Necajeva, J.; Uludag, A.; Synowiec, A.; Calha, I.M.; Lars, A.; Jensen, P.K.; et al. Comparing the emergence of *Echinochloa crus-galli* populations in different locations. Part II: Similarities and threshold parameters. *Weed Res.* **2022**, *62*, 203–214. [CrossRef]
28. Fenner, M.; Thompson, K. *The Ecology of Seeds*; Cambridge University Press: Cambridge, UK, 2005.
29. Yalamalle, V.R.; Dunna, V.; Chawla, G.; Mishra, G.P.; Vijayakumar, P.H.; Ahmad, D.; Lal, S.K.; Joshi, D.C.; Meena, R.P. Overcoming physiological dormancy in common buckwheat (*Fagopyrum esculentum* Moench). *Genet. Resour. Crop. Evol.* **2021**. [CrossRef]
30. Assche, J.A.; Vandelook, F.E. Germination ecology of eleven species of Geraniaceae and Malvaceae, with special reference to the effects of drying seeds. *Seed Sci. Res.* **2006**, *16*, 283–290. [CrossRef]
31. Makowski, R.M.; Morrison, I.N. The Biology of Canadian Weeds: 91. *Malva pusilla* Sm.(=*M. rotundifolia* L.). *Can. J. Plant Sci.* **1989**, *69*, 861–879. [CrossRef]
32. Azad, S.; Manik, M.R.; Hasan, S.; Matin, A. Effect of different pre-sowing treatments on seed germination percentage and growth performance of *Acacia auriculiformis*. *J. For. Res.* **2011**, *22*, 183. [CrossRef]
33. Olatunji, D.; Maku, J.O.; Odumefun, O.P. The effect of pre-treatments on the germination and early seedlings growth of *Acacia auriculiformis* Cunn. Ex. Benth. *Afr. J. Biotechnol.* **2013**, *7*, 325–330.
34. Aliero, B.L. Effects of sulphuric acid, mechanical scarification and wet heat treatments on germination of seeds of African locust bean tree, *Parkia biglobosa*. *Afr. J. Biotechnol.* **2004**, *3*, 179–181.
35. Amusa, T.O. Effects of three pre-treatment techniques on dormancy and germination of seeds of *Afzelia africana* (Sm. Ex pers). *J. Hortic. For.* **2011**, *3*, 96–103.
36. Dada, C.A.; Kayode, J.; Arowosegbe, S.; Ayeni, M.J. Effect of scarification on breaking seed dormancy and germination enhancement in *Annona muricata* L. *World Sci. News* **2019**, *126*, 136–147.
37. Rincon, R.; Culebro, N.; Gutierrez, F.A.; Dendooven, L. Scarification of seeds of *Acacia angustissima* Mill Kuntze and its effect on germination. *Seed Sci. Technol.* **2003**, *31*, 301–307. [CrossRef]
38. Elmore, C.L. *Weed Control by Solarization: Soil Solarization*; CRC Press: Boca Raton, FL, USA, 1991; pp. 61–72.
39. Li, X.; Baskin, J.M.; Baskin, C.C. Physiological dormancy and germination requirements of seeds of several North American *Rhus* species (Anacardiaceae). *Seed Sci. Res.* **1999**, *9*, 237–245. [CrossRef]
40. Argel, P.J.; Paton, C.J. Overcoming legume hardseededness. In *Forage Seed Production Volume 2: Tropical and Sub-Tropical Species*; Loch, D.S., Ferguson, J.E., Eds.; CABI Publishing: New York, NY, USA, 1999; pp. 247–266.
41. Barbosa, V.L.; Ruiz, C.; Correa, E.C.; Pérez-García, F. Dormancy imposed by a tough seed coat in *Malvella sherardiana* (Malvaceae), a highly threatened species of Spain. *Bot. Lett.* **2016**, *163*, 321–327. [CrossRef]
42. Gupta, R.K.; Das, S.K. Fracture resistance of sunflower seed and kernel to compressive loading. *J. Food Eng.* **2000**, *46*, 1–8. [CrossRef]