



RESEARCH ARTICLE

Seed germination characteristics of chocolate weed (*Melochia corchorifolia* L.): Responses to flooding and mulching regimes

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Abstract

Red weed (*Melochia corchorifolia* L.), locally known as chocolate weed, is an aggressive annual broad-leaved weed widely prevalent in tropical agro-ecosystems. Its rapid growth and ecological plasticity cause severe interference during crop establishment in both upland and lowland systems of the Onattukara Sandy Plain of Kerala, India. To elucidate the effects of seed scarification, paddy straw mulching and flooding on germination behaviour, pot culture experiments were conducted under rain-shelter conditions at the Onattukara Regional Agricultural Research Station, Kayamkulam. The experiments were laid out in a completely randomized design with 2 factors: seed scarification (non-scarified and mechanically scarified) as the first factor and different rates of paddy straw mulching (0, 250, 500, 750 and 1000 g m⁻²) and flooding depths (0, 1, 2, 3, 4, 5, 6 and 7 cm) as the second factor. Scarified seeds exhibited higher germination percentage, faster germination, lower mean germination time, earlier attainment of 50 % germination and superior germination indices compared to non-scarified seeds. Flooding strongly inhibited germination, with a progressive decline as water depth increased. Complete suppression was achieved at a flooding depth of ≥ 4 cm, irrespective of scarification. In contrast, paddy straw mulching did not significantly influence germination or germination indices, even at higher mulch levels. Overall, *M. corchorifolia* germination is governed primarily by dormancy release through scarification and hydrological conditions rather than surface mulching. Management strategies emphasising minimal soil disturbance and maintenance of ≥ 4 cm flooding are therefore more effective in managing red weed in rice-based systems of the Onattukara Sandy Plain.

Keywords: *Melochia corchorifolia*; paddy straw mulch; rice-based cropping system; scarification; seed dormancy; weed germination

Introduction

Rice-based cropping systems are one of the predominant agricultural systems in the wetlands of Kerala, exhibiting considerable diversity across regions and agro-ecological situations. Among these, the rice-sesame cropping sequence is traditionally practised in the wetland areas of the Onattukara Sandy Plain, covering parts of Kollam, Alappuzha and Pathanamthitta districts and is regarded as one of the most sustainable and economically viable production systems in the region. However, in recent years, the productivity of this system has been increasingly threatened by the rapid spread of red weed (*Melochia corchorifolia* L.), locally known as chocolate weed. Weeds remain a major biotic constraint in rice-based systems of Kerala and *M. corchorifolia*, once confined to upland situations, has now expanded into lowland agro-ecosystems, posing a serious menace to rice and sesame cultivation, particularly during the kharif and summer seasons. Its prolific seed production, seed mimicry (weed seeds look, feel, or mature like crop seed) and close association with sesame seeds have facilitated rapid dissemination across the region. A recent statewide assessment revealed that *M. corchorifolia*, earlier restricted to localised patches, has undergone rapid spatial expansion and emerged as a widespread weed threat in rice and sesame production systems (1).

Melochia corchorifolia is an annual herbaceous to shrubby plant native to the Old-World tropics (2) and is widely distributed across tropical and subtropical regions of Asia, Africa and Australia (3). It belongs to the family Malvaceae, a broad-leaved weed with a chromosome number of $2n = 4x = 28$ (4). The species is characterised by erect growth, pubescent stems and leaves, ovate, alternately arranged leaves, axillary and terminal inflorescences and fruits that dehisce longitudinally into 5 compartments upon maturity (4). The plant can grow up to 2 m tall and flowers and fruits throughout the year, contributing to its persistence (5).

The competitive ability of *M. corchorifolia* has been well documented. Yield losses of up to 67 % in upland rice due to annual weeds, including *M. corchorifolia*, have been reported (6). The species alone contributed 58 % of total weed dry matter in dry-sown rice at 40 days after sowing (DAS) and is recognised as a dominant weed in upland and lowland rice ecosystems, as well as in soybean (5, 7). In the Onattukara Sandy Plain, *M. corchorifolia* has emerged as the dominant weed in summer sesame, exhibiting 100 % frequency and causing yield reductions of nearly 60 % under weedy conditions (8, 9). Effective weed management increased sesame yields by about 2.5-fold, underscoring its yield-limiting potential.

Traditional control measures such as hand weeding are labour-intensive, while chemical control is constrained by phytotoxicity risks in sesame. The seed bank established during sesame cultivation serves as a major source of infestation in subsequent kharif rice, particularly under semi-dry direct-seeded conditions. Since the spread of *M. corchorifolia* is entirely seed-mediated, understanding seed ecology, especially germination behaviour and dormancy mechanisms, is crucial for sustainable management. Previous studies indicate that physical dormancy imposed by a hard seed coat limits germination and that scarification significantly enhances germination (3, 10).

Mulching has emerged as an eco-friendly weed management practice and the rice-rice-sesame system of the Onattukara Sandy Plain generates abundant paddy straw suitable for mulching. Additionally, weed infestation is generally lower in flooded transplanted rice compared to direct-seeded rice and flooding has been identified as an effective, economical cultural strategy for weed suppression (10). Therefore, evaluating the effects of flooding and mulching on the germination and germination indices of *M. corchorifolia* is essential for developing integrated, location-specific weed management strategies in rice-based cropping systems

Materials and Methods

Experimental site and time

Pot culture experiments were conducted under a rain shelter at the Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam, Alappuzha, Kerala, India, to evaluate the germination behaviour and indices of *M. corchorifolia* under different mulching and flooding regimes. The mulching experiment was carried out during August 2024 and January 2025, while the flooding experiment was conducted during September 2024 and April 2025. These periods represent the major cropping seasons of the Onattukara region of Kerala.

Experimental design and treatments

The experiments were laid out in a completely randomized design (CRD) with a factorial arrangement and 3 replications. Each treatment consisted of 3 pots per replication. In both experiments, the first factor was seed scarification with 2 levels: non-scarified seeds and mechanically scarified seeds. In the mulching experiment, the second factor was paddy straw mulch applied at 5 levels: 0, 250, 500, 750 and 1000 g m⁻². In the flooding experiment, the second factor was flooding depth imposed at eight levels: 0 (no flooding), 1, 2, 3, 4, 5, 6 and 7 cm.

Seed collection and scarification

Mature seed capsules of *M. corchorifolia* were collected one month before experimentation from rice fields at ORARS, Kayamkulam, Kerala, India (9°10'43" N, 76°31'8" E; 8.63 m above mean sea level). The fields had been under a rice-rice-sesame cropping system for several years and consisted of sandy loam soil. Seeds were manually extracted from the capsules, air-dried for 2 weeks, cleaned by sieving to remove impurities and stored in airtight plastic containers until use. Mechanical scarification was carried out by rubbing the seeds against fine-grade emery cloth (grit size 220) placed on a wooden board, moving the seeds approximately 10 cm back and forth 3 times (11).

Sowing and treatment application

Cylindrical cement pots measuring 25 cm in height and 27 cm in diameter were used for the mulching experiment, while polyethylene pots of 20 cm height and diameter were used for the flooding experiment. All pots were filled with sandy loam soil collected from the F-block of the ORARS farm. The soil was acidic (pH 4.9) with an electrical conductivity of 0.01 dS m⁻¹ and contained 0.5 % organic carbon, 326 kg ha⁻¹ available nitrogen, 52 kg ha⁻¹ available phosphorus and 238 kg ha⁻¹ available potassium. Before filling, the soil was sterilised by autoclaving at 121 °C under a pressure of 1.5 atm for 2 hr to ensure uniform experimental conditions. For the mulching experiment, sterilised soil was filled in each pot to a depth of 18 cm. 25 seeds were counted, surface-sterilised with distilled water and sown uniformly in 5 equidistant rows, with 5 seeds per row per pot, followed by light irrigation. The seeds were covered with a 2 cm layer of soil to promote uniform germination (3). Irrigation was provided as required to maintain adequate soil moisture throughout the experimental period.

Well-dried paddy straw collected from the ORARS farm was used as the mulching material. Mulch was applied at rates of 0, 14.5, 29.0, 43.5 and 58.0 g pot⁻¹, corresponding to field-equivalent application rates of 0, 250, 500, 750 and 1000 g m⁻², respectively, based on the surface area of the pots. For the flooding experiment, polyethylene pots were filled with sterilised soil to a depth of 12 cm and gently irrigated before sowing. 25 seeds were uniformly sown in each pot and covered with a 2 cm layer of soil. In the Onattukara region, kharif rice is generally sown under dry field conditions and weed emergence typically occurs following pre-monsoon showers. With the onset of the southwest monsoon, the fields subsequently become flooded. To simulate these field conditions and to assess the tolerance of early-established seedlings to submergence, flooding treatments were imposed at 3 DAS. Thereafter, water depths of 0, 1, 2, 3, 4, 5, 6 and 7 cm were maintained according to the respective treatments throughout the experimental period.

Observations recorded

Seedlings were considered germinated when the cotyledons emerged above the soil surface. Seedling counts were recorded daily up to 14 DAS. Germination parameters and indices, including germination percentage, speed of germination, mean daily germination, mean germination time, time to 50 % germination (T₅₀), germination rate index, germination index and coefficient of rate of germination, were computed on the 14th day after sowing.

Germination parameters were assessed using standard indices:

Germination percentage (%)

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100 \quad (\text{Eqn. 1})$$

Speed of germination (SG)

$$SE = \frac{n_1}{d_1} + \frac{n_2}{d_2} + \dots + \frac{n_x}{d_x} \quad (\text{Eqn. 2})$$

Where n_1 is the number of seedlings germinated on the 1st day, n_2 is the number of seedlings germinated on the 2nd day, and n_x is the number of seedlings germinated on the x^{th} day, d_1 is the 1st day, d_2 the 2nd day and d_x the x^{th} day (12).

Mean daily germination (MDG) (% d⁻¹)

$$\text{MDG} = \text{Germination percentage} / \text{Total number of days} \quad (13)$$

(Eqn. 3)

Mean germination time (MGT) (d⁻¹)

$$\text{MGT} = \sum(n_i \times t_i) / \sum N_i \quad (Eqn. 4)$$

Where n_i - no. of seeds germinated on the i^{th} day, t_i - days from sowing to the i^{th} day and N_i - total no. of germinated seeds (14).

Time to 50 % germination (T₅₀) (Days)

$$T_{50} = t_i + [(N/2 - n_i)(t_j - t_i) / (n_j - n_i)] \quad (Eqn. 5)$$

Where N = Final number of germinated seeds, n_i , n_j = Cumulative germination before and after 50 % germination and t_i , t_j = Corresponding time (days) (15).

Germination rate index (GRI)

$$\text{GRI} = (G_1 \times 100)/1 + (G_2 \times 100)/2 + \dots + (G_n \times 100)/n \quad (Eqn. 6)$$

Where G_1 and G_2 are the germination percentage on the 1st and 2nd day after sowing and G_n is the germination percentage on the n^{th} day after sowing (16).

Germination index (GI)

$$Gi = (14 \times n_1) + (13 \times n_2) + \dots + (1 \times n_{14}) \quad (Eqn. 7)$$

Where $n_1, n_2, \dots, n_{14}$ are the numbers of seedlings germinated on the first, second and subsequent days until the 14th day; 14, 13... and 1 are weightage assigned to the number of seedlings germinated on the 1st, 2nd and 14th day, respectively (17).

Coefficient of rate of germination (CRG)

$$\text{CRG} = \sum N_i / \sum (n_i \times t_i) \times 100 \quad (Eqn. 8)$$

Where n_i - no. of seeds germinated on the i^{th} day, t_i - days from sowing to the i^{th} day and N_i - total no. of germinated seeds (18).

Statistical analysis

The data were analysed using analysis of variance (ANOVA) appropriate for a factorial CRD, following the methodology described by Panse and Sukhatme (19). Treatment effects were tested using the F-test (20) and least significant difference (LSD) values were calculated at $p < 0.05$ to compare treatment means. The data which required transformation were transformed appropriately. All statistical analyses were performed using RAISINS, an integrated R- and AI-based agricultural data analysis package developed by scientists at Kerala Agricultural University (21).

Results and Discussion**Effect of scarification and depth of flooding on germination and germination indices**

Seedling germination of *M. corchorifolia* was first observed at 4 days after sowing (DAS). Germination percentage was significantly influenced by both seed scarification and flooding depth in experiments I and II (Table 1). Scarified seeds (S_2) recorded significantly higher germination than non-scarified seeds (S_1) across all flooding regimes. Non-scarified seeds exhibited extremely low germination ($\approx 2\%$) in both experiments, indicating the presence of strong physical dormancy.

Flooding depth exerted a pronounced suppressive effect on germination. The highest germination (51 %) was recorded under

non-flooded conditions (0 cm). Germination declined progressively with increasing flooding depth and was completely inhibited at ≥ 4 cm flooding. Similar trends were observed in both experiments, confirming the consistency of response to flooding depth. The interaction between scarification and flooding depth was significant, indicating that scarification partially mitigated the adverse effects of shallow flooding (1–2 cm) but failed to overcome the inhibitory effects of deeper flooding. Complete inhibition of germination at ≥ 4 cm flooding may be attributed to seed and seedling decay caused by oxygen deficiency, restricted gaseous exchange and impaired metabolic activity under anaerobic conditions (10). These results demonstrate that while scarification alleviates dormancy constraints, flooding depth ultimately governs seedling germination in *M. corchorifolia*. Similar suppression of weed germination at 2 cm flooding and complete inhibition of *Ludwigia hyssopifolia* at 2.5 cm have been reported earlier (10, 22). The inhibition observed at ≥ 4 cm flooding is also consistent with previous findings (23). Moreover, the declining trend in germination with increasing water depth agrees with observations in *Fimbristylis miliacea*, where prolonged flooding progressively reduced germination and growth as water depth increased from 0–10 cm (24).

Speed of germination was significantly higher in scarified seeds than in non-scarified seeds in both experiments (Table 1). Scarified seeds recorded values of 2.87 and 2.85 in experiments I and II, respectively, whereas non-scarified seeds showed very low values (0.15), reflecting delayed and sparse germination. Increasing the flooding depth caused a gradual and significant reduction in the speed of germination. The highest values were recorded under non-flooded conditions, while flooding depths ≥ 4 cm drastically reduced germination speed. Even under scarified conditions, the speed of germination declined sharply with increasing water depth. Interaction effects revealed that scarified seeds under non-flooded and shallow flooding conditions germinated fastest, whereas deeper flooding nullified the benefits of scarification.

Germination rate index was strongly influenced by both scarification and flooding depth (Table 2). Scarified seeds recorded significantly higher germination rate index values (≈ 67) compared to non-scarified seeds (3–4) in both experiments, reflecting faster and more uniform germination. Flooding caused a progressive decline in germination rate index, with maximum values under non-flooded conditions. The germination rate index was extremely low at ≥ 4 cm, indicating near-complete suppression of germination. The significant interaction effect indicated that scarification enhanced germination performance only under favourable non-flooded or shallow flooded conditions, while increasing flooding depths overwhelmed the positive effects of scarification.

Germination index followed trends similar to germination rate index (Table 2). Scarified seeds recorded significantly higher values (>100), whereas non-scarified seeds remained below 7, confirming poor germination performance. Flooding depth exerted a strong negative effect, with the highest values under non-flooded conditions and a sharp decline as flooding depth increased. Complete suppression at ≥ 4 cm flooding resulted in negligible germination index values. Under higher flooding depths, oxygen limitation and prolonged submergence restricted enzymatic activity and seed metabolism, resulting in poor germination even in scarified seeds (10).

Table 1. Effect of scarification and depth of flooding on germination parameters

Treatments	Germination percentage (%)		Speed of germination	
	Exp - I	Exp - II	Exp - I	Exp - II
Scarification (S)				
S ₁ – Non-scarified seeds	0.02 ± 0.04 ^b (0.12)	0.02 ± 0.04 ^b (0.12)	0.15 ± 0.16 ^b	0.15 ± 0.14 ^b
S ₂ – Scarified seeds	0.23 ± 0.34 ^a (0.39)	0.24 ± 0.35 ^a (0.41)	2.87 ± 1.39 ^a	2.85 ± 1.42 ^a
CD (0.05)	0.02	0.02	0.05	0.07
Depth of flooding (D)				
D ₁ – 0 cm	0.51 ± 0.43 ^a (0.81)	0.51 ± 0.45 ^a (0.81)	3.05 ± 2.75 ^a	2.97 ± 2.72 ^a
D ₂ – 1 cm	0.32 ± 0.33 ^b (0.52)	0.34 ± 0.36 ^b (0.54)	2.27 ± 2.30 ^b	2.37 ± 2.40 ^b
D ₃ – 2 cm	0.14 ± 0.15 ^c (0.32)	0.16 ± 0.17 ^c (0.35)	1.74 ± 1.75 ^c	1.78 ± 1.80 ^c
D ₄ – 3 cm	0.00 ± 0.00 ^d (0.07)	0.01 ± 0.02 ^d (0.09)	1.35 ± 1.37 ^d	1.32 ± 1.34 ^d
D ₅ – 4 cm	0.00 ± 0.00 ^d (0.07)	0.00 ± 0.00 ^d (0.07)	1.10 ± 1.11 ^e	1.06 ± 1.07 ^e
D ₆ – 5 cm	0.00 ± 0.00 ^d (0.07)	0.00 ± 0.00 ^d (0.07)	0.91 ± 0.93 ^f	0.89 ± 0.91 ^f
D ₇ – 6 cm	0.00 ± 0.00 ^d (0.07)	0.00 ± 0.00 ^d (0.07)	0.86 ± 0.88 ^f	0.84 ± 0.86 ^f
D ₈ – 7 cm	0.00 ± 0.00 ^d (0.07)	0.00 ± 0.00 ^d (0.07)	0.81 ± 0.83 ^f	0.77 ± 0.79 ^f
CD (0.05)	0.03	0.04	0.11	0.15
Scarification (S) × Depth of Flooding (D)				
S ₁ D ₁	0.12 ± 0.02 ^d (0.35)	0.11 ± 0.02 ^d (0.33)	0.55 ± 0.08 ^h	0.49 ± 0.06 ^h
S ₁ D ₂	0.02 ± 0.01 ^e (0.13)	0.02 ± 0.01 ^e (0.13)	0.17 ± 0.04 ⁱ	0.19 ± 0.03 ⁱ
S ₁ D ₃	0.00 ± 0.01 ^f (0.09)	0.01 ± 0.01 ^{ef} (0.10)	0.15 ± 0.04 ⁱ	0.15 ± 0.04 ⁱ
S ₁ D ₄	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	0.10 ± 0.03 ⁱ	0.10 ± 0.02 ⁱ
S ₁ D ₅	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	0.10 ± 0.02 ⁱ	0.09 ± 0.02 ⁱ
S ₁ D ₆	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	0.07 ± 0.02 ⁱ	0.06 ± 0.02 ⁱ
S ₁ D ₇	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	0.06 ± 0.02 ⁱ	0.06 ± 0.02 ⁱ
S ₁ D ₈	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	0.05 ± 0.02 ⁱ	0.05 ± 0.02 ⁱ
S ₂ D ₁	0.91 ± 0.04 ^a (1.27)	0.92 ± 0.00 ^a (1.28)	5.55 ± 0.22 ^a	5.45 ± 0.10 ^a
S ₂ D ₂	0.62 ± 0.03 ^b (0.91)	0.67 ± 0.06 ^b (0.96)	4.37 ± 0.15 ^b	4.55 ± 0.35 ^b
S ₂ D ₃	0.28 ± 0.04 ^c (0.56)	0.32 ± 0.04 ^c (0.60)	3.34 ± 0.09 ^c	3.42 ± 0.27 ^c
S ₂ D ₄	0.00 ± 0.00 ^f (0.07)	0.01 ± 0.02 ^{ef} (0.12)	2.60 ± 0.14 ^d	2.54 ± 0.14 ^d
S ₂ D ₅	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	2.11 ± 0.16 ^e	2.03 ± 0.06 ^e
S ₂ D ₆	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	1.76 ± 0.05 ^f	1.71 ± 0.12 ^f
S ₂ D ₇	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	1.66 ± 0.03 ^{fg}	1.63 ± 0.08 ^{fg}
S ₂ D ₈	0.00 ± 0.00 ^f (0.07)	0.00 ± 0.00 ^f (0.07)	1.56 ± 0.04 ^g	1.49 ± 0.03 ^g
CD (0.05)	0.04	0.05	0.15	0.21

*Values in parentheses are transformed means; original values were subjected to arcsine transformation [arcsine (√X)]. Exp - I and II represents experiment I and II, respectively. Treatments with same letter grouping are not significantly different.

Table 2. Effect of scarification and depth of flooding on germination parameters

Treatments	Germination rate index		Germination index	
	Exp - I	Exp - II	Exp - I	Exp - II
Scarification (S)				
S ₁ – Non-scarified seeds	3.58 ± 3.46 ^b	3.44 ± 3.02 ^b	6.35 ± 7.79 ^b	6.00 ± 6.65 ^b
S ₂ – Scarified seeds	67.58 ± 30.95 ^a	67.02 ± 31.67 ^a	109.82 ± 70.19 ^a	110.38 ± 72.25 ^a
CD (0.05)	1.3	1.66	2.16	3.02
Depth of flooding (D)				
D ₁ – 0 cm	68.76 ± 62.30 ^a	66.50 ± 61.40 ^a	135.11 ± 120.18 ^a	131.44 ± 120.04 ^a
D ₂ – 1 cm	52.08 ± 52.70 ^b	54.69 ± 55.06 ^b	97.22 ± 98.89 ^b	103.50 ± 104.97 ^b
D ₃ – 2 cm	41.69 ± 41.53 ^c	42.46 ± 42.49 ^c	69.67 ± 69.17 ^c	72.56 ± 72.77 ^c
D ₄ – 3 cm	34.68 ± 35.37 ^d	33.75 ± 34.13 ^d	50.28 ± 51.39 ^d	49.28 ± 49.93 ^d
D ₅ – 4 cm	27.03 ± 27.17 ^e	26.07 ± 26.24 ^e	36.39 ± 36.60 ^e	35.33 ± 35.45 ^e
D ₆ – 5 cm	21.46 ± 21.79 ^f	20.99 ± 21.47 ^f	27.06 ± 27.48 ^f	26.77 ± 27.40 ^f
D ₇ – 6 cm	20.09 ± 20.61 ^{fg}	19.74 ± 20.20 ^{fg}	25.28 ± 25.99 ^f	24.83 ± 25.48 ^f
D ₈ – 7 cm	18.85 ± 19.33 ^g	17.65 ± 18.25 ^g	23.67 ± 24.36 ^f	21.77 ± 22.54 ^f
CD (0.05)	2.60	3.31	4.33	6.03
Scarification (S) × Depth of flooding (D)				
S ₁ D ₁	11.96 ± 1.44 ^h	10.47 ± 1.15 ^h	25.55 ± 3.09 ^h	21.89 ± 2.83 ^h
S ₁ D ₂	4.01 ± 1.04 ⁱ	4.61 ± 0.48 ⁱ	7.00 ± 2.00 ⁱ	8.00 ± 1.21 ⁱ
S ₁ D ₃	3.81 ± 0.73 ⁱ	3.83 ± 0.99 ⁱ	6.55 ± 1.07 ⁱ	6.45 ± 1.90 ⁱ
S ₁ D ₄	2.45 ± 0.65 ⁱ	2.66 ± 0.60 ⁱ	3.45 ± 1.07 ⁱ	3.89 ± 0.96 ⁱ
S ₁ D ₅	2.36 ± 0.51 ⁱ	2.14 ± 0.35 ⁱ	3.22 ± 0.69 ⁱ	3.00 ± 0.67 ⁱ
S ₁ D ₆	1.59 ± 0.58 ⁱ	1.46 ± 0.41 ⁱ	2.00 ± 0.88 ⁱ	1.88 ± 0.52 ⁱ
S ₁ D ₇	1.28 ± 0.41 ⁱ	1.34 ± 0.46 ⁱ	1.56 ± 0.51 ⁱ	1.66 ± 0.58 ⁱ
S ₁ D ₈	1.21 ± 0.54 ⁱ	1.00 ± 0.54 ⁱ	1.45 ± 0.69 ⁱ	1.22 ± 0.70 ⁱ
S ₂ D ₁	125.56 ± 4.74 ^a	122.53 ± 2.47 ^a	244.67 ± 9.45 ^a	241.00 ± 3.46 ^a
S ₂ D ₂	100.14 ± 3.45 ^b	104.77 ± 7.31 ^b	187.44 ± 5.12 ^b	199.00 ± 13.53 ^b
S ₂ D ₃	79.58 ± 2.36 ^c	81.09 ± 5.99 ^c	132.78 ± 3.01 ^c	138.67 ± 11.06 ^c
S ₂ D ₄	66.91 ± 3.38 ^d	64.84 ± 3.40 ^d	97.11 ± 4.55 ^d	94.67 ± 7.23 ^d
S ₂ D ₅	51.70 ± 4.37 ^e	50.01 ± 1.53 ^e	69.56 ± 6.95 ^e	67.67 ± 2.31 ^e
S ₂ D ₆	41.34 ± 1.27 ^f	40.51 ± 2.93 ^f	52.11 ± 1.84 ^f	51.67 ± 4.16 ^f
S ₂ D ₇	38.90 ± 0.64 ^{fg}	38.13 ± 2.18 ^{fg}	49.00 ± 0.67 ^{fg}	48.00 ± 3.46 ^{fg}
S ₂ D ₈	36.49 ± 0.86 ^g	34.30 ± 0.73 ^g	45.89 ± 1.26 ^g	42.33 ± 1.15 ^g
CD (0.05)	3.68	4.68	6.12	8.53

*Exp - I and II represents experiment I and II, respectively. Treatments with same letter grouping are not significantly different.

Effect of scarification and mulching on germination and germination indices

Seedling germination of *M. corchorifolia* was first observed at 4 DAS. Germination percentage was strongly influenced by seed scarification in both experiments (Table 3). Scarified seeds (S_2) consistently exhibited substantially higher germination than non-scarified seeds (S_1). Germination of scarified seeds reached 88 % and 77 % in experiments I and II, respectively, whereas non-scarified seeds recorded only 3 and 4 %. The slightly higher germination of non-scarified seeds during experiment II may be attributed to elevated temperatures in January, corresponding to the summer season in the Onattukara region. Higher temperatures are known to weaken hard, impermeable seed coats, thereby partially alleviating physical dormancy (25, 26). In contrast, scarified seeds had already undergone seed coat disruption and were therefore less responsive to temperature-induced dormancy release. The marked enhancement in germination following scarification can be attributed to the breakdown of physical dormancy, increased seed coat permeability and improved water imbibition, which together facilitate rapid metabolic activation and uniform germination. Seeds with hard, impermeable seed coats are known to persist longer in the soil seed bank and germinate primarily after mechanical disturbance (27). Similar responses to scarification have been reported earlier in *Melochia* species (28).

Mulching did not significantly affect germination percentage in either experiment. Germination under different mulch levels remained comparable, ranging from 45–47 % in experiment I and 39–42 % in experiment II, indicating that paddy straw mulch did not suppress seed germination. This suggests that mulching primarily influences post-germination microclimatic conditions, such as soil moisture conservation and temperature buffering, rather than the physiological processes governing germination (29). Earlier studies have also reported limited sensitivity of *Melochia* species to residue mulching, in contrast to grass weeds such as *Echinochloa* and *Eleusine*, whose germination is strongly suppressed by paddy straw residues (28). No significant interaction between scarification and

mulching was observed. The speed of germination differed significantly between scarified and non-scarified seeds in both experiments (Table 3). Scarified seeds recorded markedly higher values, indicating rapid and synchronised germination. In experiment I, scarified seeds recorded a value of 5.27 compared to 0.12 in non-scarified seeds, while in experiment II, values were 4.28 and < 0.20, respectively. Mulching did not significantly affect the speed of germination in experiment I. However, in experiment II, increasing mulch levels slightly reduced the speed of germination, particularly at 1000 g m⁻², although this effect was minor compared to the dominant influence of scarification. Germination was marginally faster in experiment I, likely due to more favourable moisture and environmental conditions.

Mean daily germination followed trends similar to the speed of germination. Scarified seeds recorded significantly higher mean daily germination (6.3 and 5.5 in experiments I and II, respectively), whereas non-scarified seeds remained below 0.32. Mulching did not significantly influence this parameter. Mean germination time was significantly reduced by scarification in both experiments, with scarified seeds completing germination faster (4.4 and 4.9 days) than non-scarified seeds (6.9 and 6.88 days). In experiment II, higher mulch levels slightly increased mean germination time, particularly at 1000 g m⁻², indicating minor delays under heavier residue cover. Scarification significantly reduced the time required to reach 50 % germination (T_{50}) in both experiments (Table 4). Scarified seeds attained T_{50} within 2.2–3.0 days, whereas non-scarified seeds required 5.7–7.2 days. Mulching had no significant effect on T_{50} in experiment I, while in experiment II, higher mulch levels slightly increased T_{50} . Germination rate index was markedly higher in scarified seeds than in non-scarified seeds in both experiments. Scarified seeds recorded values of 118 and 96, whereas non-scarified seeds recorded only 4.1 and 2.57. Mulching effects were non-significant in experiment I but became significant in experiment II, where increasing mulch levels reduced germination rate index, particularly at higher mulch loads. Germination index exhibited a similar response. Scarified seeds recorded values of 234.29 and

Table 3. Effect of scarification and mulching on germination parameters

Treatments	Germination percentage (%)		Speed of germination		Mean daily germination (% d ⁻¹)		Mean germination time (d ⁻¹)	
	Exp - I	Exp - II	Exp - I	Exp - II	Exp - I	Exp - II	Exp - I	Exp - II
Scarification (S)								
S_1 - Non-scarified seeds	0.03 ± 0.01 ^b (0.17)	0.04 ± 0.01 ^b (0.21)	0.12 ± 0.04 ^b	0.19 ± 0.08 ^b	0.20 ± 0.05 ^b	0.32 ± 0.10 ^b	6.91 ± 1.06 ^a	6.88 ± 1.31 ^a
S_2 - Scarified seeds	0.88 ± 0.03 ^a (1.23)	0.77 ± 0.03 ^a (1.07)	5.27 ± 0.20 ^a	4.28 ± 0.34 ^a	6.32 ± 0.22 ^a	5.50 ± 0.18 ^a	4.40 ± 0.12 ^b	4.91 ± 0.51 ^b
CD (0.05)	0.03	0.02	0.11	0.1	0.13	0.11	0.66	0.56
Paddy straw as mulch (M)								
M_1 - No mulching	0.47 ± 0.48 (0.73)	0.41 ± 0.38 (0.65)	2.79 ± 2.90	2.39 ± 2.31 ^a	3.37 ± 3.41	2.90 ± 2.73	5.76 ± 1.97	5.20 ± 1.24 ^c
M_2 - Mulching at 250 g m ⁻²	0.46 ± 0.47 (0.70)	0.42 ± 0.41 (0.65)	2.72 ± 2.83	2.36 ± 2.34 ^a	3.27 ± 3.34	2.97 ± 2.91	5.52 ± 1.46	5.15 ± 1.06 ^c
M_3 - Mulching at 500 g m ⁻²	0.45 ± 0.47 (0.69)	0.41 ± 0.40 (0.65)	2.69 ± 2.82	2.31 ± 2.33 ^{ab}	3.24 ± 3.34	2.95 ± 2.89	5.52 ± 1.42	5.93 ± 1.36 ^{bc}
M_4 - Mulching at 750 g m ⁻²	0.45 ± 0.47 (0.69)	0.41 ± 0.40 (0.64)	2.66 ± 2.80	2.19 ± 2.24 ^b	3.24 ± 3.34	2.90 ± 2.87	5.65 ± 1.52	6.20 ± 1.41 ^{ab}
M_5 - Mulching at 1000 g m ⁻²	0.45 ± 0.47 (0.68)	0.39 ± 0.39 (0.62)	2.61 ± 2.77	1.92 ± 1.98 ^c	3.19 ± 3.32	2.81 ± 2.80	5.83 ± 1.48	6.98 ± 1.45 ^a
CD (0.05)	NS	NS	NS	0.16	NS	NS	NS	0.88

*Values in parentheses are transformed means; original values were subjected to arcsine transformation [arcsine (√X)]. Exp - I and II represents experiment I and II, respectively. Treatments with same letter grouping are not significantly different.

Table 4. Effect of scarification and mulching on germination parameters

Treatments	Time to 50 % germination (Days)		Germination rate index		Germination index		Coefficient of rate of germination	
	Exp - I	Exp - II	Exp - I	Exp - II	Exp - I	Exp - II	Exp - I	Exp - II
Scarification (S)								
S ₁ - Non-scarified seeds	7.20 ± 2.08 ^a	5.75 ± 2.36 ^a	2.57 ± 0.99 ^b	4.09 ± 1.80 ^b	5.80 ± 1.83 ^b	9.07 ± 3.44 ^b	14.80 ± 2.34 ^b	15.18 ± 3.72 ^b
S ₂ - Scarified seeds	2.25 ± 0.08 ^b	2.97 ± 0.87 ^b	118.97 ± 4.67 ^a	96.26 ± 8.12 ^a	234.29 ± 8.67 ^a	194.29 ± 12.55 ^a	22.72 ± 0.61 ^a	20.57 ± 1.95 ^a
CD (0.05)	1.24	0.95	2.55	2.47	4.77	4.54	1.48	1.78
Paddy straw as mulch (M)								
M ₁ - No mulching	4.54 ± 3.37	3.21 ± 1.51 ^{cd}	63.12 ± 65.75	53.94 ± 52.35 ^a	124.67 ± 128.92	106.94 ± 102.85 ^a	18.85 ± 5.38	20.04 ± 4.05 ^a
M ₂ - Mulching at 250 g m ⁻²	4.10 ± 2.65	2.91 ± 0.84 ^d	61.32 ± 63.95	53.01 ± 52.89 ^{ab}	120.78 ± 125.18	106.06 ± 105.35 ^a	19.09 ± 4.45	20.04 ± 3.73 ^a
M ₃ - Mulching at 500 g m ⁻²	4.93 ± 3.10	4.42 ± 2.47 ^{bc}	60.73 ± 63.84	51.92 ± 52.62 ^{ab}	119.67 ± 125.04	104.33 ± 104.83 ^a	19.07 ± 4.48	17.60 ± 3.83 ^{ab}
M ₄ - Mulching at 750 g m ⁻²	4.97 ± 3.06	4.90 ± 2.42 ^{ab}	59.88 ± 63.14	49.30 ± 50.78 ^b	118.56 ± 124.20	100.78 ± 102.51 ^a	18.68 ± 4.46	16.82 ± 3.78 ^b
M ₅ - Mulching at 1000 g m ⁻²	5.07 ± 3.28	6.36 ± 2.28 ^a	58.80 ± 62.45	42.70 ± 44.19 ^c	116.56 ± 123.04	90.28 ± 92.41 ^b	18.11 ± 4.57	14.88 ± 3.19 ^b
CD (0.05)	NS	1.5	NS	3.9	NS	7.18	NS	2.81

*Exp - I and II represents experiment I and II, respectively. Treatments with same letter grouping are not significantly different.

194.29 in experiments I and II, respectively, compared to 5.80–9.07 in non-scarified seeds. Mulching effects were negligible in experiment I but showed a declining trend in experiment II. The coefficient of rate of germination was significantly higher in scarified seeds, reflecting faster and more synchronised germination. Scarified seeds recorded values above 22.0, whereas non-scarified seeds remained below 15.2 in both experiments. Mulching had no significant influence on this parameter, confirming that seed coat permeability rather than surface residue governs germination kinetics of *M. corchorifolia*.

Conclusion

The present investigation demonstrates that seed scarification is the primary determinant of germination and early establishment of *M. corchorifolia*, confirming that physical dormancy imposed by a hard, impermeable seed coat is the main constraint to germination. While paddy straw mulching did not significantly suppress germination, flooding exerted a strong inhibitory effect, with germination declining progressively with increasing water depth and completely inhibited at ≥ 4 cm, even in scarified seeds. From a weed management perspective, minimising soil disturbance to prevent seed coat damage, together with maintaining flood depths ≥ 4 cm, emerges as an effective cultural strategy to suppress germination. Integrating reduced tillage with appropriate water management can therefore provide an ecologically sustainable approach for managing *M. corchorifolia* in rice-based cropping systems of the Onattukara Sandy Plain.

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Authors' contributions

SP executed the experiment, collected the data and prepared the manuscript. PYPI, SPP, SKR, MV and TG conceptualised, supervised the experiment and revised the manuscript. All authors read and approved the final manuscript.

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