



RESEARCH ARTICLE

Emergence dynamics of Chinese sprangletop (*Leptochloa chinensis* (L.) Nees.) in wet direct-seeded lowland rice

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Abstract

Chinese sprangletop (*Leptochloa chinensis* (L.) Nees.) is a C₄ grass that closely resembles rice at the seedling stage, often leading to delayed identification and significant yield losses. Understanding the conditions that favour emergence and survival is essential for characterising its growth dynamics in humid tropical systems; accordingly, seed germination was evaluated under a range of environmental stresses. Germination studies were conducted under laboratory conditions and as pot culture experiments at the College of Agriculture, Vellayani, which experiences a humid tropical climate. Although light triggered germination, it was not identified as an essential requirement for seedling emergence. The highest cumulative germination (87 %) occurred at a fluctuating temperature regime of 25/15 °C, indicating that alternating temperatures can favour germination of buried seeds of *L. chinensis*. The emergence pattern of the seed and rhizome differed markedly. Seeds exhibited higher emergence when placed on the soil surface and showed limited ability to emerge from deeper layers. In contrast, emergence from rhizomatous underground stems bearing nodal roots was observed up to a depth of 4 cm, but not beyond. Higher seed germination immediately after maturity (87 %) suggests options for soil seed bank management, with implications for stale seedbed techniques involving propagule exposure followed by shallow tillage for crop establishment. Seeds were observed to retain viability under prolonged flooding, with 45 % germination even after 30 days, demonstrating the resilient nature of the weed. However, aerobic conditions with alternate irrigation promoted higher germination (70 %) and establishment, suggesting that mild moisture fluctuations can trigger emergence, ascribing its dominance in direct-seeded rice systems. Continuous flooding or maintaining a shallow water layer substantially suppressed germination and emergence. The study identified deep seed burial and continuous flooding as factors that could limit the germination and establishment of *L. chinensis* in wetland rice.

Keywords: alternating temperature; burial depth; dormancy flooding; germination; light; salinity; seed viability

Introduction

Leptochloa chinensis (L.) Nees, commonly known as Chinese sprangletop or red sprangletop, is a widely distributed C₄ grass that has become one of the most troublesome weeds in rice ecosystems (1, 2). Native to tropical Asia, it now occurs throughout South and Southeast Asia, East Africa, Australia, North America and several Pacific islands (3). This annual invasive weed spreads swiftly because of its low dormancy and high seed production, enabling it to colonise rice systems globally (4). The species infests dry-seeded rice in more than 16 countries and wet-seeded systems in several others, with outbreak levels comparable to *Echinochloa crus-galli*, traditionally regarded as the dominant competitor in rice (3). In southern India, particularly Kerala, *L. chinensis* was historically associated with alkaline soils, but it now thrives even in acidic environments, contributing to pronounced weed shifts (5).

Leptochloa chinensis is known to be an invasive weed in

Southeast Asia (6). Botanically, it is an annual with glabrous leaves and hollow culms, completing its life cycle within a growing season through seed production. However, under favourable conditions, it behaves as a short-lived perennial; forming dense tufts up to 150 cm tall and profuse rhizomatous underground stems with nodal roots that support rapid vegetative spread. Nodes can root even when detached, enabling secondary and tertiary branching that imparts a perennial-like growth habit. Though seeds are the main form of reproduction, fragmentation of rhizomatous underground stems during agricultural production further accelerates field invasion, like in other perennial sedges (7, 8). The species is highly adaptable, colonising croplands and waterways across varied soil textures and moisture regimes. It grows rapidly and competes aggressively with rice through nodal rooting and prolific tillering, leading to yield losses of up to 84 % in field experiments (4). Yield losses primarily result from its close morphological resemblance to rice during early growth stages. In wet-seeded rice (WSR) systems, season-long

competition by *L. chinensis* often goes unnoticed and has been reported to cause yield reductions of up to 59.95 % (9).

The widespread shift from transplanted to direct-seeded rice (DSR) across Asia has intensified *L. chinensis* proliferation with direct seeding exposing rice fields to early-emerging grasses and sedges, while repeated application of herbicides with similar modes of action has driven weed shifts and resistance (10, 11). In Kerala, continuous use of bispyribac sodium for barnyard grass control has facilitated the dominance of *L. chinensis* in transplanted systems (12). Herbicide mixtures with novel modes of action can broaden control spectra and delay resistance, but their effective use requires a clear understanding of weed germination ecology and its response to agronomic and environmental factors (13). However, limited knowledge of the mechanisms governing weed establishment continues to constrain long-term management.

Germination and emergence of *L. chinensis* are governed by key environmental factors such as light, temperature, moisture, salinity and burial depth (14). Light sensitivity determines whether seeds germinate on or near the soil surface, a trait that becomes particularly important under DSR, where surface seed exposure is high and residue cover is low. Temperature fluctuations can act as stimulants by modulating phytochrome activity in buried seeds (15). The moisture regime in flooded or intermittently flooded rice ecosystems has a strong influence on the pattern of emergence and should be taken into account in chemical and cultural control methods. The depth of burial is also important, as small-seeded grasses have a significantly reduced emergence when buried even a few centimetres.

Rising salinity driven by sea-level rise increasingly threatens rice ecosystems, stressing the need to understand how salt stress influences *L. chinensis* germination and establishment. Despite its growing prominence in DSR systems, knowledge of its germination ecology under humid tropical conditions remains limited. As a *C₄* species, its competitive advantage may intensify under future climate scenarios (16). Against this backdrop, the present study investigated the germination and emergence behaviour of *L. chinensis* across light, temperature, moisture, salinity and burial-depth gradients to formulate more effective and sustainable management strategies.

Materials and Methods

Experiments were conducted at College of Agriculture, Vellayani (8°29' N, 40°9' E), Thiruvananthapuram, Kerala, India. Mature seeds of *L. chinensis* were collected from major rice-growing tracts of Kuttanad (9°35' N, 76°40' E), Kole (10°20' N, 75°58' E) and Palakkad (10°48' N, 76°54' E). Panicles were collected from more than 100 arbitrarily selected plants and shattered seeds were bulked, cleaned and stored in airtight containers at room temperature for six months until use. Experiments were repeated over time, with the

second run initiated within one month of completing the first and the data were pooled for analysis.

Effect of light and temperature on germination

To evaluate the effects of light regimes and temperature on *L. chinensis* germination, 100 intact seeds were placed in Petri dishes lined with moistened filter paper (5 mL distilled water). Dishes were incubated in growth chambers at two fluctuating day/night temperature regimes (35/25 and 25/15 °C) under either a 12 hr light/12 hr dark cycle or continuous darkness, as specified in Table 1, which is representative of the typical tropical temperature fluctuations. Petri dishes assigned to the dark treatment were wrapped in three layers of aluminium foil to prevent light entry. Seeds were considered germinated upon radicle emergence and germination was recorded at three-day intervals up to 15 days.

Effect of salinity on germination

The effect of salt stress on *L. chinensis* germination was assessed by placing 20 seeds in Petri dishes containing 5 mL of NaCl solutions at 0, 25, 50, 100, 150, 200 and 250 mM using sodium chloride of molecular weight 58.44 and the dishes were incubated in growth chambers under light. Seeds failing to germinate at the highest salinity levels were rinsed under running water for 5 min and re-incubated with 5 mL distilled water to assess recovery. Germination was recorded at three-day intervals for up to 15 days.

Effect of moisture conditions on germination and seedling emergence

The effect of different moisture regimes on seed germination and seedling emergence was evaluated through a pot experiment. Pots (27 cm diameter, 22 cm height) without drainage holes were uniformly filled with soil from a lowland rice field. The experiment followed a completely randomised design with four replications. Ten seeds of the weed were sown in pots and maintained under five simulated field moisture conditions representing five moisture regimes viz., moist soil irrigated on alternate days (*T*₁); continuously flooded lowland conditions with 5 cm standing water (*T*₂); alternating flooding and drainage, with five days of flooding followed by 5 days without flooding (*T*₃); moist soil maintained under 1 cm water layer through daily irrigation (*T*₄); and soil irrigated to a depth of 5 cm once in every 15 days (*T*₅). Germination was recorded at three-day intervals for up to 30 days.

Effect of seed burial depth and means of propagation on seedling emergence and weed survival

The effect of burial depth on *L. chinensis* emergence was evaluated in a pot experiment. Pots (27 cm diameter, 22 cm height) without drainage holes were filled with soil collected from lowland rice fields. Seeds and rhizomatous underground stem bits bearing nodal roots were placed on the soil surface and covered to burial depths of 0, 2, 4, 6 and 10 cm. Pots were irrigated to field capacity on alternate days. Seedling emergence, defined by the appearance of

Table 1. Effect of light and alternating temperatures and salinity levels on seed germination of *Leptochloa chinensis*

Days after sowing (DAS)	Germination of <i>Leptochloa chinensis</i> (%)				Germination of <i>Leptochloa chinensis</i> (%)						
	12 hr light/dark		24 hr dark		Salinity (NaCl concentration) (mM)						
	35/25 °C	25/15 °C	35/25 °C	25/15 °C	0	25	50	100	150	200	250
3	0	0	0	0	25	10	0	0	0	0	0
6	30	46.25	10	21.25	75	60	20	10	0	0	0
9	35	50	10	30	85	80	50	35	20	10	10
12	65	80	65	65	85	80	65	55	45	40	30
15	65	80	65	65	85	85	70	65	50	50	45

visible coleoptiles at the soil surface, was recorded at three-day intervals up to 30 days after sowing (DAS). Emergence from the stem bits was monitored at the same intervals for 30 days.

Statistical analysis

The data were analysed using the WASP two statistical package (ICAR-Goa, India) by performing analysis of variance (ANOVA). Germination or emergence (%) was modelled as a function of time under different light regimes, temperature fluctuations, salt concentrations, burial depths and moisture conditions. Non-linear regression analyses were carried out in GRAPES 1.0.0, developed by the Kerala Agricultural University and a three parameter sigmoid model provided the best fit, with R^2 values >0.99. Germination responses to alternating temperatures and salt concentrations were described using the following equation.

$$G = G_{\max} / \{1 + e^{[-(T - T_{50})/G_{\text{rate}}]}\} \quad (\text{Eqn. 1})$$

Where G is the total germination (%) at time T, $G_{\max}$ is the maximum germination (%), T_{50} is the time required for 50 % of maximum germination and G_{rate} indicates the slope.

Results

Effect of light and temperature on germination

In our study, light was not found essential for the germination of *L. chinensis* seeds. However, it enhanced germination by 23 %

(Fig. 1). Seeds incubated in darkness also germinated, reaching a maximum of 65 % at both 35/25 and 25/15 °C. Dark conditions reduced germination at optimal temperatures, indicating marked photoblastism, although germination rates were similarly rapid under both light and dark conditions. Under alternating temperature regimes in light/dark conditions, seeds germinated across all tested ranges (Fig. 2). Maximum germination (87 %) occurred at 25/15 °C, compared with 70.31 % at 35/25 °C, with cumulative germination 19 % higher at 25/15 °C. Time to 50 % germination was 7.2 days at 25/15 °C and 8.0 days at 35/25 °C, with the latter regime producing the lowest cumulative germination and the longest T_{50} .

Effect of salinity on germination

Germination of *L. chinensis* was not markedly affected at lower salinity levels, with ≥ 70 % germination recorded from 0–50 mM NaCl. Germination declined thereafter but remained >60 % up to 100 mM (Fig. 3). Even at 150 mM NaCl, 50 % of the seeds germinated and germination at 150 to 250 mM remained above 40 %. The salt concentration required for 50 % inhibition of maximum germination was 150 mM. The higher the salinity, the longer the time to germination onset, with the time to 50 % germination increasing from four days at 0 mM to 11 days at 200 mM. When non-germinated seeds, which had been treated with 250 mM for 15 days, were washed with distilled water, the germination was restored to 60–70 %, suggesting that the osmotic inhibition was

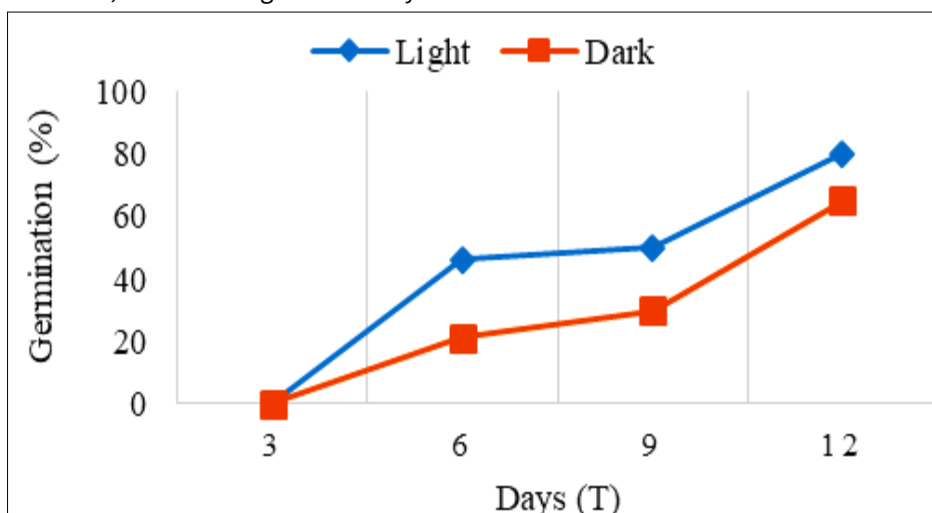


Fig. 1. Germination response of *Leptochloa chinensis* seeds to light and dark conditions at 25/15 °C.

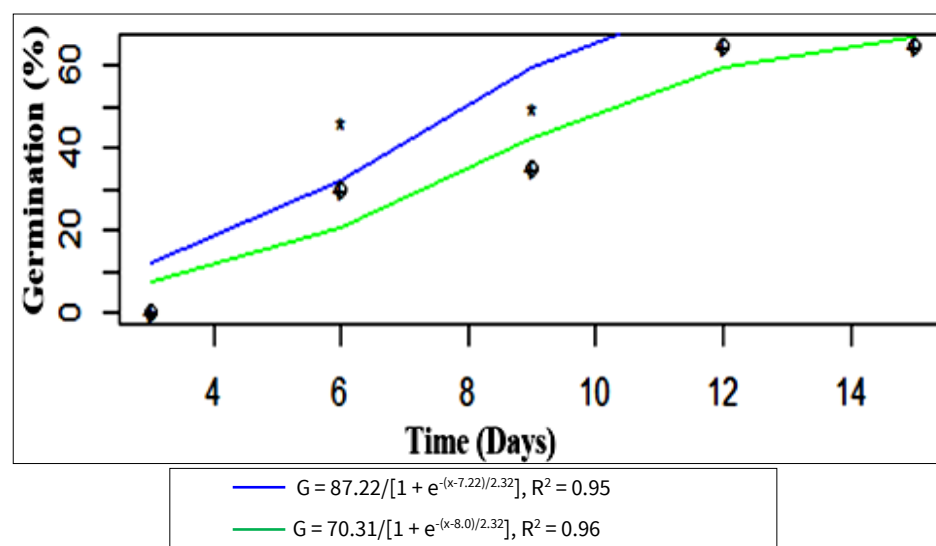


Fig. 2. Time taken for 50 % germination of seeds of *Leptochloa chinensis*.

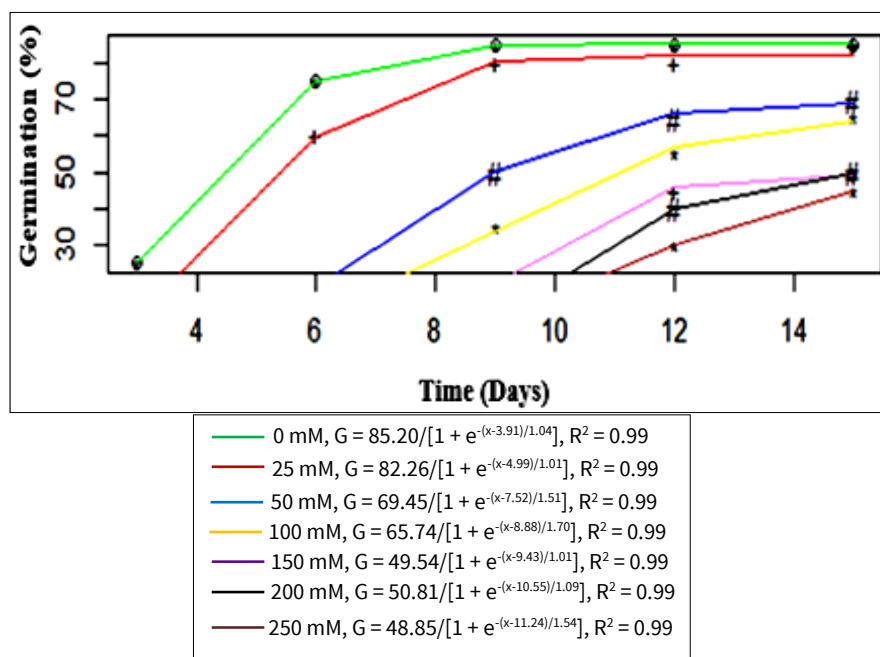


Fig. 3. Influence of NaCl concentrations (mM) on germination of *Leptochloa chinensis*. reversible.

Effect of moisture conditions on germination and seedling emergence

Germination was significantly influenced by the imposed moisture regimes. The highest germination and seedling emergence (70 %) occurred under moist conditions maintained by irrigation on alternate days (Table 2). In the alternating flooding-drainage treatment, 55 % of seeds emerged by 5 DAS, but subsequent drying following drainage killed the emerged seedlings and further irrigation did not induce additional germination. A similar pattern was observed in pots irrigated to a 5 cm depth once every 15 days, with 35 % emergence at 5 DAS, followed by complete seedling mortality due to prolonged dry periods. No germination occurred under continuous flooding or under a thin (1 cm) water layer; however, when flooding was withdrawn, 45 % of the seeds

Table 2. Effect of simulated field conditions on emergence of *Leptochloa chinensis* at 30 DAS

Treatments	Emergence (%) at 30 DAS
T ₁ Moist conditions maintained by irrigating on alternate days	56.94 (70)
T ₂ Lowland with continuous flooding	0.65 (0)
T ₃ Lowland conditions with alternate flooding and draining	0.65 (0)
T ₄ Moist conditions with a thin layer of water (3 cm)	0.65 (0)
T ₅ Soil irrigated to a 5 cm depth once in 15 days	0.65 (0)
SEm±	6.46
CD (0.05)	5.50

Data were arc-sin transformed; actual mean values are given in parentheses.

germinated and seedlings emerged. It is noteworthy that the established seedlings were not killed by flooding after emergence.

Effect of seed burial depth and means of propagation on seedling emergence and weed survival

Seedling emergence of *L. chinensis* declined sharply with increasing burial depth (Table 3). Maximum emergence (85 %) occurred when

seeds were placed on the soil surface, whereas no emergence was observed at depths ≥ 2 cm. Surface-sown seeds germinated over an extended period, with some emerging even after 30 days. Germination also varied within the inflorescence, with seeds from the tip, which mature and shatter earlier, showing higher germination than those from the middle or basal portions. Rhizomatous underground stem bits bearing nodal roots (slips) exhibited much greater emergence than seeds. Slips placed on the soil surface produced 100 % emergence and although the time to 50 % emergence increased with depth, slips buried up to 4 cm still achieved full emergence. No emergence from seeds or slips

Table 3. Effect of depth of burial and means of propagation on the survival of *Leptochloa chinensis* at 30 DAS

Treatments	Emergence/spouting (%) at 30 DAS
T ₁ Seeds buried at 0 cm depth	67.71 (85)
T ₂ Seeds buried at 2 cm depth	0.65 (0)
T ₃ Seeds buried at 4 cm depth	0.65 (0)
T ₄ Seeds buried at 6 cm depth	0.65 (0)
T ₅ Seeds buried at 10 cm depth	0.65 (0)
T ₆ Slips buried at 0 cm depth	89.35 (100)
T ₇ Slips buried at 2 cm depth	89.35 (100)
T ₈ Slips buried at 4 cm depth	89.35 (100)
T ₉ Slips buried at 6 cm depth	0.65 (0)
T ₁₀ Slips buried at 10 cm depth	0.65 (0)
SEm±	8.79
CD (0.05)	3.592

Data were arc-sin transformed; actual mean values are given in parentheses.

occurred beyond 4 cm. However, slips buried at 6 and 10 cm produced new flushes when returned to the soil surface after 30 days, indicating strong regenerative capacity.

Discussion

Light was shown to induce germination in *Leptochloa chinensis*, but germination was also observed under continuous darkness,

suggesting that light is not an absolute requirement. Similar results for dark germination have been observed for this weed species and *E. crus-galli*, suggesting that light can trigger germination but is not a necessity (17, 18). The absence of light enables a fraction of seeds to remain dormant within the soil seed bank, allowing buried seeds to persist and germinate when they are brought back to the soil surface. In another study, seeds maintained in continuous darkness showed lower germination compared to seeds receiving a 12 hr light period and emergence was the highest for seeds on the soil surface and decreased with increasing depth of burial, with no seedlings emerging from 5 cm depth (19). While an absolute light requirement has been proposed, other studies have observed a significant but incomplete inhibition of germination in darkness, including *E. glabrescens* (20, 21). Although an absolute light requirement has been proposed, other research has shown a large but incomplete inhibition of germination under dark conditions, as found in *E. glabrescens*. Light-dependent traits of germination may be involved in the enhanced weed problems that can occur in no-till or reduced tillage practices where seeds are present on the soil surface (15). An understanding of the light-dependent traits of germination of *L. chinensis* is, therefore, important for the development of tillage strategies.

Temperature is an important factor in the germination of weed seeds (22). *Leptochloa chinensis* showed the highest germination (87.22 %) at 25/15 °C, which was contrary to previous findings where no germination occurred at this temperature (20). The high sensitivity to alternating temperatures suggested that temperature fluctuations stimulated seed germination of *L. chinensis*. Temperature fluctuations may enhance the thermal conversion of inactive phytochrome form (pr) to biologically active (pfr) form sufficient to initiate germination under dark conditions (17). It can be inferred that diurnal temperature variations created conditions conducive to the germination of *L. chinensis* seeds buried in the soil. Temperature fluctuations can explain the frequent co-occurrence of *L. chinensis* in bare ground, where the range of temperature fluctuations is the largest (20, 23). *Leptochloa chinensis* is well suited to warm rice habitats and has optimal germination at higher temperatures, with reduced or delayed germination at lower temperatures (24). High germination rates shortly after seed maturity can be effectively used in stale seedbed methods that involve initial exposure and shallow tillage to decrease the soil seed bank.

Leptochloa chinensis exhibited high tolerance to salinity, with germination remaining largely unaffected even at elevated NaCl levels. The NaCl concentration required for 50 % inhibition of maximum germination was 150 mM. Comparable tolerance has been reported in *Echinochloa glabrescens* and *Mimosa invisa*, where germination persisted up to 250 mM (21, 22). These results contrast with earlier findings that reported no germination of *L. chinensis* at ≥ 150 mM and approximately 50 % inhibition at 50 mM (20). Though the increase in salinity caused a delay in germination, as indicated by the extended T_{50} , the seeds were able to recover to 60–70 % germination upon rinsing after treatment with 250 mM. This suggests that high salinity induces a reversible osmotic inhibition rather than causing a permanent loss of seed viability. Though these results agree with the data that show a gradual reduction in germination until 200 mM, the high germination value obtained in this experiment emphasises the high adaptability of the weed (3). However, the longevity of *L. chinensis* seeds under saline conditions remains uncertain and the strong germination response across high

salinity levels points to the chance of *L. chinensis* becoming a dominant weed in salt-stressed rice environments.

Thirty days of continuous flooding were found to be the most effective in reducing the emergence of *L. chinensis*. Flooding was more effective in reducing emergence when seeds were placed on the soil surface. Flooding up to 2 cm reduced emergence by 26 % when intermittently flooded (2 out of 7 days) and by 72 % when continuously flooded for 28 days (20). The reduction in emergence may be due to lower availability of oxygen, accumulation of CO₂ and anaerobic decomposition products. Continuous flooding may inhibit germination of light- and temperature-sensitive seeds (15). The seeds were able to germinate even after 30 days when flooding was removed, showing their ability to remain dormant until favourable conditions arise. The seedlings that emerged were also not affected by flooding, as seen in other tolerant weeds. The size of the seeds also contributed to fast emergence in well-aerated top layers (17). The residual moisture in the puddled soil supported the initial germination process, but the prolonged periods of drying did not allow the survival of seedlings. The continuous presence of a thin layer of water in the soil resulted in anaerobic conditions that completely suppressed germination. Conversely, alternate-day watering highly stimulated germination and emergence, indicating that *L. chinensis* can easily grow in aerobic, moist environments. Fast germination, together with drought-sensitive seeds and shallow-emergence of seedlings, assists *L. chinensis* in avoiding futile germination, escaping chemical control and hand weeding in rice (25). Such behaviour is responsible for its success in DSR systems, in which water availability varies greatly. Being a C₄ plant, *L. chinensis* is more drought-tolerant than C₃ rice, indicating its advantage over rice in a drought environment (16).

Emergence of *L. chinensis* was the highest from seeds placed on the soil surface, with no emergence from depths ≥ 0.5 cm, in line with earlier reports and consistent with its light-stimulated germination (20). In direct-seeded rice ecosystems, where rice is directly sown without transplanting, weeds are likely to establish and develop more easily, thus becoming a more serious threat to crop production (26). This is because less than 1 % of the incident light can penetrate beyond 2 mm of soil, which is too weak to stimulate germination (27, 28). Apart from the limitations imposed by the lack of light, the small size of the seeds, hypoxia, low diffusion of gases and CO₂ build-up would also limit emergence from deeper layers. The limited seed reserves of the weed are also likely to worsen this limitation, making the seeds in the underground layers susceptible to fatal germination (22). The wide range of germination (6–45 days) in this experiment suggested staggered emergence patterns over the growth cycle, which may help escape herbicide treatments. But rhizomatous underground stems with nodal roots showed greater potential for regeneration than seeds, with 100 % emergence at depths up to 4 cm. Bits of rhizomes planted at 6–10 cm showed the emergence of new flushes after 30 days, suggesting longevity and deep soil persistence in direct-seeded rice, like rock bulrush, which persists through rhizome bud sprouting (29). Therefore, the first deep tillage act that would place seeds below their maximum emergence depth could be an effective means of reducing seedbank recruitment and germination.

Conclusion

The variation observed compared to previous reports on light, salinity and burial responses indicates adaptation and high

ecological flexibility of *Leptochloa chinensis*. The seeds of *L. chinensis* emerged primarily from the soil surface, while slips were capable of emerging from depths up to 4 cm. Though light and fluctuating warm temperatures enhanced germination, light was not a requirement and seeds could germinate across a wide range of conditions. Flooding had a strong inhibitory effect on weed emergence and thus submergence up to the critical period of crop weed-competition (one-third of the total crop duration) could be practised in highly infested areas. The variation observed relative to earlier reports on light, salinity and burial responses suggests regional adaptation and considerable ecological plasticity in *L. chinensis*. Future studies should investigate the interactive effects of submergence and shallow tillage on the population dynamics and seed bank depletion of *L. chinensis*.

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Authors' contributions

LS performed the experiments and assisted in writing the manuscript. NJ and RB arranged the resources. AM assisted in writing the manuscript and supervised the study. SPP, GK, SK and SVS reviewed the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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