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Seed germination and emergence dynamics of late spring and winter American sloughgrass (*Beckmannia syzigachne*) accessions

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Beckmannia syzigachne is a serious annual grass weed in wheat-rice rotation systems during the wheat season in China. Typically, *B. syzigachne* sets seed in late spring, however, it has also been observed setting seed in winter since 2019. Laboratory and screenhouse experiments were conducted to evaluate seed germination and emergence dynamics of winter (Win-A) and late spring accessions (Lsp-A) of *B. syzigachne* shortly after seed collection in February and May of 2020 and 2021. Results indicated that Lsp-A seeds exhibited higher seed weight, viability and germination compared to Win-A seeds. Under natural conditions, 12% of Win-A seeds emerged in March when sown at a depth of 0.5 cm soil. These emerged plants reached anthesis and produced mature seeds by May, completing two reproductive generations within a year. Lsp-A seeds showed higher emergence rates in October (40%) and November (42%), whereas only 5% emergence was recorded during summer. To explore the potential origin of Win-A plants, Lsp-A seeds were enclosed in nylon bags and buried at a depth of 5 cm in either moist or continuously flooded soil. These burial conditions were designed to simulate rice field and field border environments following wheat harvest. Under continuous flooding, seed germination declined by 3%, 62% and 81% after 1, 2 and 3 months, respectively, with no germinations observed after 4 months. A significant reduction in emergence was noted for seeds buried under continuous flooding after 2 months. For seeds buried in moist soil and retrieved in June and July, emergence rates of 27% and 11% were observed during summer. These findings suggest that Lsp-A seeds buried in moist soil or those retrieved within 2 months of burial in flooded soil, can emerge in August and September, potentially serving as the source of *B. syzigachne* plants that set seed in winter. The rapid loss of seed viability under flooded conditions may explain why Win-A plants are primarily found along field borders in wheat-rice rotation systems. This study indicates that *B. syzigachne* has the potential to become a year-round problem.

KEYWORDS
American sloughgrass, flooding, seed dispersal, seed dormancy, wheat-rice rotation systems

1 Introduction

American sloughgrass [*Beckmannia syzigachne* (Steud.) Fernald] is one of the most damaging annual grass weed widely distributed across China. It commonly occurs in marshes, ditch margins, and various winter crop fields, including oilseed rape (*Brassica napus* L.) and wheat (*Triticum aestivum* L.). This weed prefers wet, irrigated soils but can also adapt to slightly acidic to alkaline soils with shallow water tables (Li, 1998; Rao et al., 2008). *Beckmannia syzigachne* can reach heights of 60 to 100 cm and produce more than 500 seeds per inflorescence branch. Its lightweight seeds are easily detached and dispersed by water, wind, or animals (Zhang et al., 2019; Yin et al., 2024). Among weed species in wheat fields of eastern China, *B. syzigachne* exhibits the highest dominance value (19%) and, together with *Galium aparine*, comprises over 64% of the weed community in rice-wheat rotation systems (Chen et al., 2025). In China, herbicides targeting acetyl coenzyme A carboxylase (ACCase; EC 6.4.1.2) and acetolactate synthase (ALS; EC 4.1.3.18) are widely used to control *B. syzigachne*. However, several studies have reported that this weed has developed resistance to these herbicides through both target-site or non-target-site mechanisms (Wang et al., 2020; Bai et al., 2022; Wang et al., 2023). As a result, *B. syzigachne* competes strongly with crops and leads to substantial economic losses.

The life cycle of *B. syzigachne* is closely synchronized with wheat and oilseed rape in rice-based crop rotations in the Middle and Lower Yangtze River regions of China. It is reported that *B. syzigachne* seeds show the highest germination at 20/10 °C and 25/15 °C, with >80% germination at pH 4–10, and seedling emergence declines sharply with increasing burial depth (Rao et al., 2008; Xue et al., 2026). Seedlings emerge in October, flower from March to April, and set seed by May of the following year (Boe and Wynia, 1985; Rao et al., 2008). Since 2019, some *B. syzigachne* plants on rice field borders in Fuyang District (Hangzhou, China), have been observed flowering in mid-November, with seeds maturing by February (Supplementary Figure 1). In contrast, most seedlings inside the field (after rice harvest) were at 3- to 5-leaf stage in November. This suggests that field-border *B. syzigachne* plants emerged earlier. Nevertheless, the origin of these early-flowering plants and their growth and development remain unclear.

Seed germination and dormancy behavior are key determinants of future weed infestation in crop fields (Baskin and Baskin, 2014). The rice-wheat cropping system is a traditional grain production system in the Middle and Lower Yangtze River regions. This system covers approximately 8 million hectares annually, accounting for over 35% of China's total grain output, and its alternating flooded and aerobic conditions profoundly influence weed seedbank dynamics and species composition, with *B. syzigachne* being the dominant weed (Jing et al., 2026). After dispersal from the mother plant in wheat season, *B. syzigachne* seeds may encounter varying soil conditions (flooded or moist) in the following rice season. The alternation of moist and flooded conditions under wheat-rice rotation can deplete seed reserves considerably, even in wetland-adapted species (Ma et al., 2018; Singh et al., 2022). However, the specific effects of flooding on seed viability of *B. syzigachne* have not yet been determined.

Given the significant economic impact of *B. syzigachne*, a detailed investigation of the germination and emergence characteristics of seeds collected in different seasons could contribute to the development of effective management strategies. In this study, we collected naturally mature seeds of *B. syzigachne* in winter (February) and late spring (May). The objectives of this study were to (1) compare seed weight, viability, germination and emergence dynamics of the two accessions shortly after collection; (2) evaluate the germination and emergence of the late spring-collected seeds buried at a depth of 5 cm under both moist and flooded conditions shortly after collection. The overall aim of this research is to elucidate the origin of the early-flowering (Win-A) plants, and the mechanisms that enable *B. syzigachne* to persist as a serious weed throughout the year.

2 Materials and methods

2.1 Seed collection

Mature seeds of *B. syzigachne* (collected just prior to seed shedding) were manually harvested in late spring from over 200 randomly selected inflorescences with seeds at the pale brown stage in ripening wheat fields at China National Rice Research Institute (CNRRI, 30.04N; 119.55E) in May 2020 and 2021. The seeds were cleaned, pooled and designated as the "late spring accession (Lsp-A)". Similarly, mature seeds of *B. syzigachne* were collected from the borders of the same field (which were rotated to rice after wheat harvest) in February 2020 and 2021, these were designated as the "winter accession (Win-A)". As *B. syzigachne* is an annual weed, individual Lsp-A plants die after seed maturation, eliminating the possibility of the same mother plant producing seeds in both late spring and winter. After collection, all seeds were cleaned and winnowed using a laboratory seed vacuum cleaner (CFY-II, Daji Instrument Manufacture, Hangzhou, Zhejiang, China) to ensure uniform, high-quality seeds for subsequent experiments. Laboratory and screenhouse experiments were initiated immediately after seed processing.

2.2 Characteristics of *B. syzigachne* Lsp-A and Win-A seeds

The first experiment compared the seed weight, viability, and germination of Lsp-A and Win-A seeds shortly after their reproductive collections in May and February. For seed weight evaluation, the 1000-seed weight was recorded. Seed viability was assessed using a rapid testing kit (the bromothymol blue (BTB) method, Yuanye Biotechnology Co., Ltd., Shanghai, China) according to the manufacturer's instructions. The BTB method is based on the principle that viable seeds release CO_2 during respiration, which dissolves in water to form carbonic acid, decreasing the pH of the surrounding solution and causing the BTB indicator to change from blue (alkaline/neutral) to yellow-green or yellow (acidic); non-viable seeds show minimal respiration and no color change.

For germination tests, 25 seeds were placed in 9-cm diameter Petri-dishes containing double layers of moistened filter paper (Double Ring #102, Hangzhou Special Paper Industry Co. Ltd., China). The dishes were sealed with Parafilm (American National Can, Greenwich, CT) to

minimize moisture loss and then placed in an incubator (GXZ-300C, Dongnan Instrument Manufacture, Ningbo, Zhejiang, China). The incubator was set to alternating day/night temperatures of 20/10 °C, 80% relative humidity, and a 14 h photoperiod coinciding with the high-temperature phase. These incubating conditions were based on a previous report (Rao et al., 2008) and our preliminary experiments. A seed was considered germinated when the radicle protruded by 2 mm and the coleoptiles had elongated, demonstrating a positive gravitropic response (Chauhan and Johnson, 2008). Germinated seeds were counted 21 d after the start of the experiment. Win-A seeds that did not germinate within the initial 21 d test were transferred to new Petri-dishes under the same conditions and incubated for an additional 21 d, or until no germination occurred. The total number of germinated seeds was then combined.

2.3 Seedling emergence dynamics of *B. syzigachne* Lsp-A and Win-A seeds in pots

The second experiment investigated the seedling emergence dynamics of Lsp-A and Win-A seeds sown in moist soil immediately after collection under simulated natural conditions. This study was conducted in a screenhouse (an 8 m × 60 m chamber framed with a 1-cm iron mesh and covered with a transparent plastic roof for rain protection) at CNRRI. Lsp-A seeds were tested from May to November, and Win-A seeds from February to May, in both 2020 and 2021. The soil used in this experiment was collected from upland rice fields with a pH of 6.0 and consisted of 40% sand, 32% silt, and 28% clay. The soil was air-dried in the shade, passed through a 3-mm sieve, and autoclaved at 121 °C for 25 min to eliminate any resident *B. syzigachne* seeds. Fifty seeds were sown on the surface of plastic pots (15 cm diameter, 13 cm height) and covered with a 0.5 cm layer of the same soil. The pots had drainage holes at the bottom to allow for sub-irrigation. Initial irrigation was provided by an overhead sprinkler, followed by sub-irrigation to maintain adequate soil moisture throughout the experiment. Temperatures and light in the screenhouse were similar to ambient outdoor conditions, with average temperatures of 28.5/18.2 °C (spring), 33.6/24.8 °C (summer), 22.4/14.6 °C (autumn), and 10.2/3.5 °C (winter) during the experimental periods (monthly means are shown in Supplementary Figure 3). Natural photoperiod ranged from 10.5 to 14 h, relative humidity from 60% to 85%, and passive ventilation was provided by mesh walls. A Seedling was considered emerged when its cotyledons were visibly discernible at the soil surface. Emerged seedlings were counted every 10 days after planting until no further emergence occurred. All emerged seedlings at 2-leaf stage were carefully removed from the pots and transplanted individually into separate pots for subsequent growth and reproduction observation.

2.4 Seed germination and emergence dynamics of *B. syzigachne* Lsp-A seeds buried in moist and continuous flooding conditions

The third experiment aimed to investigate the potential origin of the Win-A plants. On May 20 of 2020 and 2021, freshly collected Lsp-A seeds were placed into nylon mesh bags (4 cm × 4cm, mesh size 90 μm), with 200seeds per bag. The bags were buried 5 cm below the soil surface in two separate concrete tanks (5 m long ×1.2 m wide×1.5 m height) filled with rice field soil described in section 2.3. One tank had perforated bottom for drainage, while the other was totally water-proof. From May to November, the soil in the first tank was watered daily to maintain continuous moisture, while the second tank was kept continuously flooded. These conditions simulated the post-wheat harvest environments of rice fields and field borders, respectively. One hundred bags were buried in each tank. Four bags were exhumed monthly from each tank, rinsed with tap water, and used for germination and emergence tests in the laboratory and screenhouse. These tests were conducted on June 20, July 20, August 20, and September 20 (corresponding to 30, 60, 90, and 180 days after burial) in 2020 and 2021, respectively.

Germination test was performed followed the procedure described in Experiment 1. For the emergence test, 25 seeds from each exhumed bag were sown on the soil surface in plastic pots covered with a 0.5 cm soil layer. The soil type, pots, environmental conditions, and emergence criteria matched those described in Experiment 2. Emergence tests were conducted monthly, starting on June 20. Emerged seedlings at the 2-leaf stage were carefully transplanted into separate pots for growth and development observation. The experiment was concluded in October as most seeds buried in moist soil had germinated by then. Seedling emergence was recorded every five days, and the emergence percentage was calculated monthly until October.

2.5 Statistical analysis

All experiments were arranged in a randomized complete block design with four replications per treatment. In germination and emergence test, each replication was considered a block and was placed on a different shelf in the incubator or bench in the screenhouse. The experiments were conducted in 2020 and repeated identically during the same periods in 2021. Data from each experiment were analyzed using a two-way fixed-effects analysis of variance (ANOVA) model: $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$, where α_i represents the fixed effect of treatment (e.g., accession type, burial condition, or burial duration), β_j the fixed effect of experimental run (year: 2020 or 2021), $(\alpha\beta)_{ij}$ their interaction, and ε_{ijk} the random error. The interaction term was explicitly tested using Type III sums of squares. Since no significant interactions ($P > 0.05$) were found, data from the two experimental runs were pooled. For seed weight, viability and germination comparisons between Win-A and Lsp-A accessions in the first experiment, a two-sample Student's t-test was used after verifying normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test). Mean comparisons in the subsequent experiments were performed using Tukey's honest significant difference (HSD) test, where the overall differences were significant ($p \leq 0.05$). All analyses were conducted using SPSS software (v. 26.0; SPSS, Chicago, IL, USA).

3 Results

3.1 Characteristics of *B. syzigachne* Lsp-A and Win-A seeds

The plants of *B. syzigachne* flowering in late spring and winter were phenological similar, with no visually detectable differences in

plant morphology, inflorescence or panicle shape. However, at stages from flowering to seed maturity, Lsp-A plants were taller and more vigorous than Win-A plants, exhibiting relatively greater branching and more panicles upon visual observation (Supplementary Figure 1). The 1000-seed weight of Lsp-A was significantly higher than that of the Win-A. Seed viability and germination rate for Win-A seeds within 21 days were 33.3% and 24.0%, respectively, whereas Lsp-A seeds demonstrated 100% viability and germination shortly after collection (Table 1). These results indicate that the maturity of Win-A seeds was significantly lower. Seeds of both accessions were capable of germinating shortly after collection when incubated at their optimum temperature.

Prolonged testing of Win-A seeds revealed germination rates of 33.0% and 2.0% over the subsequent 21-d periods, resulting in a cumulative germination of 59.0% (Figure 1). This suggests that Win-A seeds germinate over a more extended period under the same environmental conditions compared to Lsp-A seeds. The recorded germination percentage for Win-A seeds was lower than their viability, a difference potentially attributable to the variation in maturity between the two accessions.

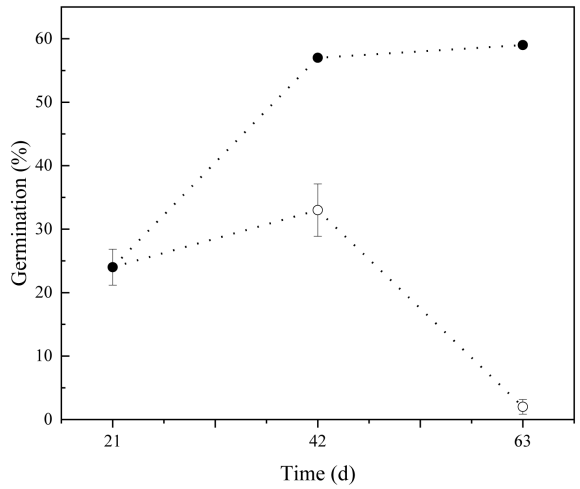


FIGURE 1
Seed germination percentage (○) and cumulative germination (•) of *B. syzigachne* winter accession (Win-A) seeds after incubated at 20/10 °C with a 14 h photoperiod. The seeds were tested immediately after collected in February. Vertical bars represent standard errors.

3.2 Seedling emergence dynamics of *B. syzigachne* Lsp-A and Win-A seeds in pots

The monthly emergence pattern of *B. syzigachne* in the screenhouse, following sowing in moist soil, differed between the Win-A and Lsp-A accessions. For Win-A seeds, seedling emergence was confined to the first two months after sowing (February 8% and March 5%) (Figure 2). The cumulative emergence of Win-A seeds was substantially lower than the laboratory-tested germination percentage, implying that some viable Win-A seeds may have germinated but fail to emerge due to soil physical constrains or insufficient vigor (germination refers to radicle protrusion in Petri dishes, whereas emergence requires successful shoot penetration through the soil surface). When the emerged seedlings were transplanted to new pots, they reached the flowering and seed maturity stages by May (Supplementary Figure 2), concurrent with the timing for Lsp-A seedlings that had emerged the previous November.

In contrast, the Lsp-A seeds sown in May shortly after collection exhibited 100% cumulative emergence, with relatively higher emergence rates in September (13%), October (40%) and November (42%). This pattern aligns with the natural life cycle previously reported for this species (Li, 1998; Rao et al., 2008). Limited emergence (1-2%) was observed during May, June and August, the hottest months of the year. Each emerged seedling was transplanted to a new pot to monitor its growth and development. Seedlings emerging in May and June were often stunted or completed their life cycle within 60 days. In contrast, seedlings emerging in late August and early September developed more rapidly under warmer pre-winter conditions, reaching the flowering stage by December or January. However, the subsequent cold temperatures during winter grain-filling restricted successful seed maturation, as a result, only a portion of these seeds (74.7%) attained full maturity.

TABLE 1 Seed weight, viability and germination of *B. syzigachne* late spring accession (Lsp-A) and winter accession (Win-A) seeds tested shortly after collection [a].

Seed biotype	1000 seed weight (mg)	Seed viability (%)	Seed germination (%)
Lsp-A seed	102.0 (2.6) a	100 (0) a	100 (0) a
Win-A seed	68.1 (1.2) b	74.7 (4.4) b	24.0 (2.8) b

[a]Data were averaged over 2 yr. SEs are in parentheses. Means within a column for seed biotype followed by the same lower letter are not different according to Student's *t* test at $P = 0.05$.

3.3 Seed germination and emergence dynamics of *B. syzigachne* Lsp-A seeds buried in moist and continuous flooding conditions

Seed germination of Lsp-A *B. syzigachne* was significantly influenced by soil moisture conditions during burial (Figure 3). Under continuous flooding, the highest germination (97%) was observed for seeds buried for 1 month, declining to 38% for seeds buried for 2 months. No germinations occurred for seeds exhumed after 4 months of continuous flooding. In contrast, seeds buried in moist soil maintained a high germination percentage (94%) even after 4 months.

The emergence patterns of Lsp-A seeds exhumed in subsequent months differed depending on whether they were buried in moist or flooded soil in May (Figure 4). For seeds exhumed in June (1 month after burial in moist soil), emergence was observed in the first two months, June (16%) and July (11%), with a major peak occurring in October and November (28% and 30%, respectively). However, no emergence was observed till September for seeds buried under flooded conditions. A similar trend was recorded for seeds from both treatment groups exhumed in July (2 months after burial). When seeds were buried for 3 months, significantly lower emergence was recorded for the flooding treatment compared to the moist soil treatment. Only 1% of seeds emerged from the 4-month flooding treatment. In general, a

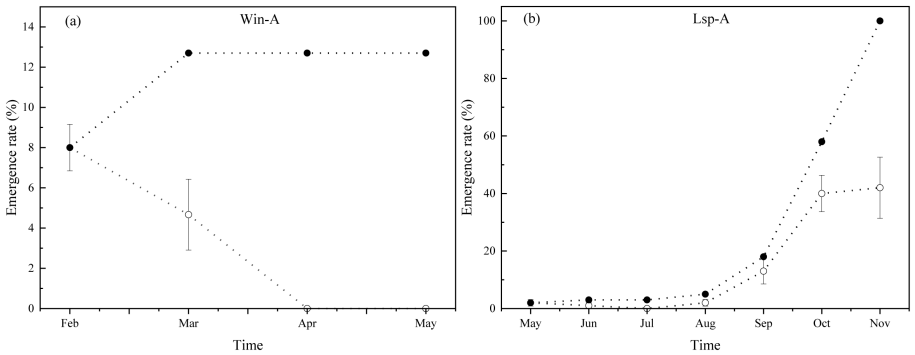


FIGURE 2
Seedling emergence percentage (○) and cumulative emergence (•) of winter accession (Win-A) **(A)** and late spring accession (Lsp-A) **(B)** *B. syzigachne* seeds after sowed in 0.5 cm soil depth in the screenhouse. The seeds were planted immediately after collected in February and May, respectively. Vertical bars represent standard errors.

major emergence peak occurred in October and November for both burial conditions, but seedling emergence for seeds exhumed from flooding was restricted to the period from September to November. These findings support the field observation that plants setting seeds in winter are primarily found in field borders or upland areas within the wheat-rice rotation system.

4 Discussion

Although the biology and ecology of *Beckmannia syzigachne* have been studied in detail in previous reports (Li, 1998; Rao et al., 2008), there is no documented evidence of *B. syzigachne* producing seeds during the less favorable cold season. This study demonstrated that *B. syzigachne* seedlings emerging from the Lsp-A accession in August and early September attained a higher leaf stage compared to those emerging in October and November.

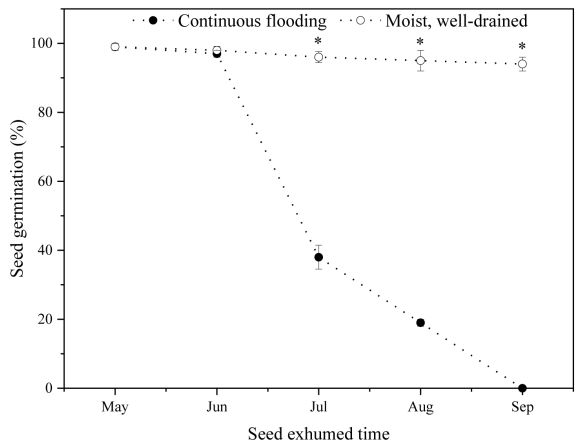


FIGURE 3
Germination percentage of *B. syzigachne* late spring accession (Lsp-A) seeds after buried in 5 cm depth under continuous flooding (•) and moist, well-drained soil (○) conditions in the screenhouse. The seeds were buried immediately after collected in 20 May. Vertical bars represent standard errors. The asterisk (*) indicates differences ($p < 0.05$) between two accessions at the same treatment time point (Tukey's test).

This observation was corroborated in wheat-rice cropping systems, where larger seedlings were found along field borders (Supplementary Figure 4). The co-occurrence of *B. syzigachne* seedlings at varying leaf stages within a field necessitates careful consideration when selecting herbicides. The ability of *B. syzigachne* to flower and set seed in both late spring and winter within wheat-rice rotation systems further suggests a broad environmental tolerance, which may facilitate its dispersal and expansion of the soil seedbank (Gao et al., 2020). Additionally, seedlings emerging from the Win-A accession in February and March may escape standard weed control measures, such as pre-emergence herbicide applications following wheat sowing (Marschner et al., 2024). These traits could render *B. syzigachne* a persistent issue throughout the year.

Significant differences in seed weight and viability were observed between the Lsp-A and Win-A seeds. This may be attributed to the less favorable growing conditions, such as cooler temperature and reduced sunlight (Supplementary Figure 3) experienced by Win-A mother plants during flowering and seed development, leading to reduced embryo nutrition and seed mass (Peltonen-Sainio et al., 2011; Nguyen et al., 2021). Previous studies also reported lower fresh weight in seeds matured under suboptimal conditions compared to those from typical maturation in weed species such as *Camelina sativa* (Wittenberg et al., 2019), *Galium aparine* (Mennan and Ngouajio, 2006), *Lolium rigidum* (Chauhan and Walsh, 2022) and *Parthenium hysterophorus* (Adkins and Shabbir, 2014; Shrestha et al., 2024). Variation in seasonal conditions during seed development strongly influences key life-history traits, including germination behavior (Luzuriaga et al., 2006; Bhatt et al., 2018; Baskin and Baskin, 2019). This may explain the lower germination of Win-A seeds compared to Lsp-A seeds under identical light and temperature in this study.

Optimal germination temperatures may vary between seeds of the same weed species collected in different seasons. For instance, while summer and winter seeds of *P. hysterophorus* germinated equally well at 30/20 °C (Shrestha et al., 2024), summer seeds exhibited much lower germination than winter seeds. In contrast, both winter and summer accessions of *L. rigidum* showed the highest germination at 25/15 °C (Bajwa et al., 2021; Thompson and Chauhan, 2022). As shown in earlier studies, environmental

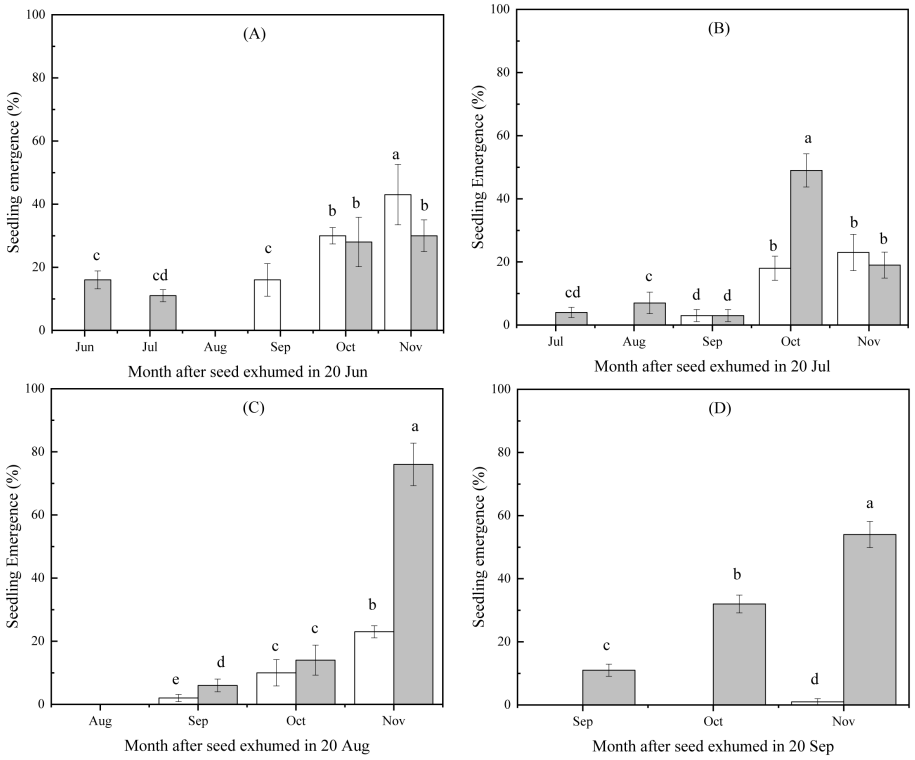


FIGURE 4
Seedling emergence percentage of late spring accession (Lsp-A) *B. syzigachne* seeds exhumed in June **(A)**, July **(B)**, August **(C)** and September **(D)** after buried in 5 cm soil depth under moist, well-drained soil (■) and continuous flooding (□) conditions. The seeds were buried immediately after collected in 20 May. Vertical bars represent standard errors. Bars designated by different lower letters are significant different ($p \leq 0.05$) among different time points between the two accessions (Tukey's test).

conditions during maternal plant flowering and seed development can influence offspring germination (Javaid et al., 2010; Baskin and Baskin, 2014; Malka et al., 2023). In the present study, cumulative germination of both Lsp-A and Win-A seeds approached their viability percentages at optimum temperatures, indicating very low dormancy in both accessions. The considerable lower emergence rate under natural conditions suggests that some Win-A seeds avoided germination at low temperatures. Further research is needed to investigate seedbank persistence and germination responses of Win-A seeds to varying temperature regimes.

The alternating moist soil and flooding conditions in wheat-rice rotation systems affect seed germination, dormancy, longevity, and ultimately seedbank persistence in both crops. A key transition from wheat to rice season involves changes in soil gas composition, such as reduced O_2, elevated CO_2, and the accumulation of toxic gases like methane, nitrogen oxides, and sulfides from anaerobic decomposition. Seed germination and dormancy in weed species are influenced by burial conditions (Smith and Fox, 1973; Pierce and King, 2007). Short-term flooding has been shown to stimulate germination in soil seedbanks, whereas prolonged flooding can reduce seed viability (Dixon, 2003; Hölzel and Otte, 2004; Wagner and Oplinger, 2017). It is believed that flooding does not affect viability of dormant weed seeds (Baskin et al., 2002; Kestring et al., 2009). Since *B. syzigachne* seeds show no innate dormancy after maturation, the significant reduction in germination and emergence following burial in flooded soil may be due to secondary dormancy induced by hypoxic or anoxic conditions (Long et al., 2015; Travlos et al., 2020; Zhou et al., 2021).

In the wheat-rice rotation systems of the middle and lower Yangtze River region, the interval between wheat harvest and rice planting is typically less than one week. Thus, seeds of weed species from the wheat season are exposed to varying soil moisture conditions shortly after maturation. While this study simulated only continuous flooding (rice field) and moist soil (field border), actual field conditions in both transplanted rice and direct-seeded rice involve alternating flooding and wet cycles according to crop water requirements. Our results suggest that shallow flooding during the rice season may effectively reduce *B. syzigachne* seedling emergence in the following wheat season.

4.1 Conclusion and practical implications

Currently, *B. syzigachne* germinates and emerges of in autumn, flowering and setting seeds in the following spring. Although winter-maturing *B. syzigachne* is not yet a widespread issue, this may change in the future. This species already exerts significant economic impacts on wheat production in China. A better understanding of its germination ecology, dormancy, phenology, flooding tolerance, and herbicide resistance is essential for assessing its adaptive potential and developing effective control strategies.

Lsp-A and Win-A accessions of *B. syzigachne* experienced contrasting climatic conditions during flowering and seed development, leading to pronounced differences in seed quality. Win-A seeds can

germinate and emerge shortly after collection in February. Together with Lsp-A seedlings emerging the previous autumn, this could enable two reproductive accessions per year. The dormancy and emergence patterns of Lsp-A seeds were significantly affected by burial conditions. Most seeds entered dormancy after 2 months of continuous flooding, suggesting that maintaining shallow water during the rice season may aid integrated management of *B. syzigachne* in subsequent wheat crops. A small portion of Lsp-A seeds retained in moist soil germinated during hot and humid months, potentially giving rise to Win-A plants.

We acknowledge that weed germination and reproduction depend on dormancy status, which is regulated under natural conditions by both seasonal cues and environmental factors. In addition, substantial variation exists among different weed accessions. Further research is needed to understand why some *B. syzigachne* seedlings can survive and set seed under winter conditions in China, based on a broader collection of winter accessions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

WT: Writing – original draft, Writing – review & editing. ML: Formal analysis, Investigation, Software, Writing – original draft. MW: Investigation, Methodology, Writing – original draft. YL: Conceptualization, Resources, Supervision, Writing – review & editing.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fagro.2026.1711911/full#supplementary-material

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