Effects of PEG-simulated drought on seed germination of the endangered plant Hopea chinensis at different temperatures: Postprint

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Abstract

Seeds of Hopea chinensis are typical recalcitrant seeds. To investigate the adaptability of seed germination to temperature and moisture, this study established three temperature regimes (15 °C, 20 °C, and 25 °C) in an artificial climate incubator and employed six mass percentage concentrations of polyethylene glycol (PEG-6000) (0, 5%, 10%, 15%, 25%, and 35%) to simulate drought stress treatments, thereby examining the germination characteristics of Hopea chinensis seeds. The results indicated that: (1) Temperature had a significant effect on seed germination. Under the same drought stress concentration, the germination percentage, germination potential, germination index, radicle length, shoot length, and vigor index of seeds showed an increasing trend with rising temperature, germination lag time decreased with increasing temperature, and germination duration exhibited a fluctuating increase with temperature elevation. (2) Drought stress had a significant effect on seed germination. At the same temperature, the germination percentage, germination potential, germination index, germination duration, radicle length, plumule length, and vigor index of seeds showed a decreasing trend with intensifying drought stress, while germination lag time increased with aggravated drought stress. (3) The interaction between temperature and drought stress had a significant effect on seed germination. Under drought stress, seed germination performance varied under different temperature conditions. Under 35% PEG-6000 stress, the seed germination percentages at 20 °C and 25 °C were 8.89% and 15.55%, respectively, which were significantly greater than that at 15 °C (0%). In summary, the temperatures suitable for seed germination were 20 °C and 25 °C, with 25 °C being optimal for early seedling growth. The greater the drought severity, the stronger the inhibitory effect on seed germination; drought stress exerted a greater influence on seed germination than temperature, and appropriate temperature elevation could alleviate the inhibitory effect of drought stress on seed

germination.

Full Text

Effects of Simulated Drought by PEG-6000 on the Germination of *Hopea chinensis* Seeds Under Different Temperature Conditions

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Abstract

Hopea chinensis seeds are typical recalcitrant seeds. To investigate their germination adaptability to temperature and moisture, this study examined seed germination characteristics under three temperature regimes (15 °C, 20 °C, and 25 °C) and six polyethylene glycol (PEG-6000) concentrations (0, 5%, 10%, 15%, 25%, and 35%) simulating drought stress in artificial climate incubators. The results revealed: (1) Temperature significantly affected seed germination. Under the same drought stress concentration, germination rate, germination energy, germination index, radicle length, shoot length, and vitality index increased with rising temperature, while germination delay decreased and germination duration showed fluctuating increases. (2) Drought stress significantly impacted seed germination. At the same temperature, all germination parameters decreased with intensifying drought stress, while germination delay increased. (3) The interaction between temperature and drought stress significantly influenced germination, with seeds showing different performance across temperatures under drought stress. Under 35% PEG-6000 stress, germination rates at 20 °C and 25 °C were 8.89% and 15.55%, respectively, significantly higher than at 15 °C (0%). In conclusion, the suitable temperatures for seed germination are 20 °C and 25 °C, with 25 °C being optimal for early seedling growth. Greater drought intensity increasingly inhibits seed germination, and drought stress exerts a stronger effect than temperature, though appropriate warming can alleviate drought-induced inhibition.

Keywords: endangered plant, *Hopea chinensis*, temperature, drought stress, seed germination

Introduction

Seed germination represents a critical stage in plant population regeneration and is highly sensitive to environmental pressures (Li et al., 2007). Successful germination and seedling emergence depend on multiple ecological factors (Yu et al., 2006), and the capacity to adapt to environmental changes reflects a plant's ecological strategy (Lei et al., 2020). Different plant species require distinct germination conditions and exhibit varying adaptive responses, making the investigation of ecological factors' effects on seed germination a persistent research focus (Lei et al., 2020; Fan et al., 2021; Guan et al., 2022).

Temperature and moisture are among the most important ecological factors influencing seed germination. Some species benefit from alternating temperatures (Guan et al., 2022), while others require constant temperature (Yu et al., 2004), high temperature (Yu et al., 2004), or low temperature (Sheng et al., 2004). Plant responses to water stress during germination vary considerably, with numerous scholars employing PEG-6000 solutions to simulate drought stress and assess germination-stage drought resistance (Li et al., 2013; Yan et al., 2016). Low-concentration drought stress can promote germination in some species (Wang et al., 2016); for example, PEG-6000 solutions at 0.05–0.10 $g \cdot ml^{-1}$ enhanced germination and seedling uniformity in *Metasequoia glyptostroboides* (Wu et al., 2020), and 5%–10% PEG-6000 treatments broke seed dormancy in *Rhododendron xiaoxidongense* (Li et al., 2022). However, as PEG-6000 concentration increases, germination inhibition intensifies (Wang et al., 2016; Chen et al., 2017), with germination rate and index declining accordingly (Liu, 2019). Temperature and moisture interactively affect germination; moderate warming can alleviate high-concentration PEG stress inhibition in *Vicia unijuga* seeds (Tang and Nan, 2019), while *Caragana korshinskii* seeds show strongest drought tolerance at lower temperatures (Yan et al., 2016). Investigating temperature and moisture requirements for germination, particularly in endangered species, helps elucidate germination characteristics, population dynamics, and ecological adaptability (Steven, 1991), providing theoretical foundations for conservation and restoration strategies (Zhang et al., 2018).

Hopea chinensis (Dipterocarpaceae) is an evergreen tree species, a nationally protected second-class wild plant in China, a species with extremely small populations, and is listed as Critically Endangered (CR) by the International Union for Conservation of Nature. Previous research has focused on population ecology (Huang et al., 2008), photosynthetic characteristics (Mo et al., 2009), seedling physiology (Zhou et al., 2013), pollination biology (Lu et al., 2020), seed distribution patterns and germination characteristics (Tang et al., 2009), and seed physiological traits (Huang et al., 2022). These studies have advanced understanding of its population ecology and biological characteristics. *H. chinensis* seeds have high moisture content, lack dormancy, and readily germinate in warm, humid environments (Huang et al., 2008). In natural habitats, seeds falling on rocks rapidly desiccate and lose viability (Tang et al., 2009). Huang et al. (2022) reported that after eight days of natural dehydration, germination rate dropped to only 51.67%, approaching the lethal threshold, suggesting drought as a critical factor affecting germination. Additionally, seeds stored at 12–13 °C under moist conditions showed poor germination (37%) when sown after 25 days (Huang et al., 2008). Since *H. chinensis* seeds mature from December to January during Guangxi's cool winter, low temperature may be another important limiting factor. The species' flora has tropical affinities requiring warm-humid germination conditions, yet the specific effects of temperature and moisture on its germination remain unclear. This study investigates germination characteristics under different temperatures and PEG-6000 concentrations to explore: (1) adaptive mechanisms under varying temperature and drought stress; (2) response strategies to different temperature and drought conditions; and (3) differences in germination under interactive temperature and drought treatments. The findings will help identify optimal ecological conditions for germination and provide theoretical support for germplasm conservation and seedling cultivation.

Materials and Methods

1.1 Experimental Materials Seeds were collected in January 2020 from Nanshan Protection Station of Guangxi Fangcheng Golden Camellias National Nature Reserve (108°02 33 E, 21°43 34 N, elevation 196 m, south-facing slope, 10° gradient). The 1000-seed weight was 470.73 g with 42.57% moisture content. All seeds were mature and naturally abscised from mother trees. After collection, seeds were mixed thoroughly, immediately transported to the Guangxi Key Laboratory of Superior Trees Resource Cultivation, cleaned of impurities, and used for germination experiments. All collection activities were permitted by local management authorities.

1.2.1 Drought Stress Simulation Using PEG-6000 Under Different Temperatures Following Chen et al. (2017), six PEG-6000 concentrations (0 [distilled water], 5%, 10%, 15%, 25%, and 35%) were prepared to simulate drought stress. Each treatment had three replicates of 30 healthy, wingless seeds. Seeds were disinfected in 0.2% potassium permanganate solution for 5 minutes, rinsed, and soaked in distilled water for 24 hours. They were then placed in 120 mm petri dishes lined with two layers of filter paper and 10 mL of PEG-6000 solution. Based on native climate conditions and preliminary experiments, dishes were incubated at 15 °C, 20 °C, or 25 °C under 3,000 lx light for 12 h/d at 80% relative humidity. Filter paper and PEG-6000 solutions were replaced every two days.

1.2.2 Seed Viability and Germination Characteristics Germination was recorded daily when radicles reached half the seed length. The 20-day experiment concluded with measurements of radicle length (Lr) and shoot length (Ls). Germination indices included germination percentage (GP), germination index (GI), germination delay (GD), germination duration (D), germination energy (GE), and vitality index (VI), calculated as follows (Yan et al., 2016; Lei et al., 2020):

- GP = (Total germinated seeds / Total seeds tested) × 100%
- GI = Σ(Number of seeds germinated on day t / Corresponding germination day)
- GD = Time required from incubation start to first seed germination
- D = Time required for the germination process
- GE = (Number of normally germinated seeds within 7 days / Total seeds tested) × 100%
- VI = GI × (Lr + Ls)

Where Lr and Ls are radicle length (cm) and shoot length (cm) at experiment termination (in this study, seedling root length represents the total length of radicle and hypocotyl).

1.3 Data Analysis SPSS 19.0 was used for ANOVA and Duncan's multiple range tests on germination indices across treatments. Two-way ANOVA examined interactive temperature and drought stress effects ($P < 0.05$). Statistical significance was set at $\alpha = 0.05$ for all analyses.

Results

2.1 Effects of Different Temperatures on Seed Germination As shown in Table 1 , under 0% PEG-6000, germination rate, germination energy, germination index, and radicle length at 20 °C and 25 °C were significantly greater than at 15 °C, while germination delay was significantly shorter. Specifically, germination rates were 0.59 and 0.56 times higher than at 15 °C, germination energy was 1.1 and 1.2 times higher, germination index was 0.87 and 0.46 times higher, and vitality index was 3.44 and 4.95 times higher, respectively. At 25 °C, germination duration, radicle length, shoot length, and vitality index reached maximum values of 14.3 days, 6.28 cm, 6.56 cm, and 27.62, respectively, with germination duration, radicle length, and vitality index significantly exceeding the other two temperatures.

Under 5% PEG-6000 stress, germination rate and energy at 20 °C and 25 °C were significantly greater than at 15 °C, being 0.42 and 0.46 times higher for germination rate, and 1.0 and 1.11 times higher for germination energy. At 25 °C, germination index, duration, radicle length, shoot length, and vitality index were maximal, with germination index, duration, radicle length, and vitality index significantly exceeding other temperatures.

Under 10% PEG-6000 stress, germination rate, energy, and index at 20 °C and 25 °C were significantly greater than at 15 °C. Germination rates were 0.48 and 0.33 times higher, germination energy was 1.75 and 2.0 times higher, germination index was 0.77 and 0.75 times higher, germination delay was 0.35 times shorter, and germination duration was 0.44 and 0.12 times longer than at 15 °C. At 25 °C, radicle length, shoot length, and vitality index were maximal, with radicle length and vitality index significantly exceeding other temperatures.

Under 15% PEG-6000 stress, germination rates across all temperatures fell below 50%, reaching the semi-lethal threshold. At 25 °C, germination energy, radicle length, shoot length, and vitality index were maximal. Under 25% PEG-6000 stress, 25 °C yielded maximal germination rate, germination index, radicle length, and vitality index, with minimal germination delay—0.23 and 0.28 times shorter than at 20 °C and 15 °C, respectively. Radicle length was 0.21 and 0.35 times longer than at 20 °C and 15 °C, and vitality index was 1.42 times higher than at 15 °C.

Under 35% PEG-6000 stress, germination rates were lowest across all temperature treatments, with germination occurring only at 20 °C (8.89%) and 25 °C (15.55%), indicating severe inhibition.

2.2 Effects of Different PEG-6000 Concentrations on Seed Germination At 15 °C, germination rate, energy, index, radicle length, and vitality index under 0% and 5% PEG-6000 were significantly greater than other concentrations. Germination delay under 0%, 5%, and 10% PEG-6000 was significantly shorter than the remaining three concentrations. Germination duration under 0%, 5%, 10%, and 15% PEG-6000 was significantly longer than the other two concentrations.

At 20 °C, germination rate, index, and vitality index under 0% PEG-6000 were significantly greater than other concentrations. Germination delay under 0%, 5%, and 10% PEG-6000 was significantly shorter than the remaining three concentrations. Germination duration under 0% and 5% PEG-6000 was significantly shorter than under 10% PEG-6000, showing a trend of initial increase then decrease with intensifying drought.

At 25 °C, germination rate, index, radicle length, shoot length, and vitality index under 0% and 5% PEG-6000 were significantly greater than other concentrations, with significantly shorter germination delay. Germination energy and duration under 0% PEG-6000 were significantly greater than other concentrations.

2.3 Interaction Between Temperature and PEG-6000 Simulated Drought Stress Table 2 shows that temperature, PEG-6000 simulated drought stress, and their interaction had highly significant effects ($P < 0.01$) on all eight germination indices. Differential seed responses to PEG-6000 stress across temperatures reflected this interaction. For example, under 5% PEG-6000, germination rates at 20 °C and 15 °C differed by 24.44% (82.22%

vs. 57.78%). Under 10% PEG-6000, the difference between 20 °C and 15 °C decreased to 22.22% (68.89% vs. 46.67%) compared to the 5% concentration.

Discussion and Conclusion

Seed germination requires suitable ecological conditions, with interacting factors influencing seed viability (Yu et al., 2006). Our results demonstrate that at 20 °C and 25 °C, *H. chinensis* seeds exhibited high germination rates, energy, index, and vitality, with longer radicles and shoots and shorter germination delays. Conversely, at 15 °C, these parameters were minimal, shoots failed to grow, and germination was inhibited, indicating 20–25 °C as the optimal temperature range. Notably, germination duration was significantly shorter at 20 °C than at 25 °C, suggesting faster overall germination, while seeds at 25 °C began germinating by day 2 with maximal radicle and shoot lengths, making it ideal for early seedling growth. Appropriate temperatures maintain high enzyme activity, accelerating enzymatic reactions, respiration, and nutrient mobilization to meet germination demands (Qin et al., 2020). Extreme temperatures alter hydrolase properties and membrane permeability, inhibiting germination (Song et al., 2010). Optimal germination temperatures reflect adaptation to native habitats (Li et al., 2021). Inhibition at 15 °C aligns with findings for other tropical recalcitrant seeds like *Shorea wantianshuea* and *Pometia pinnata* (Wen et al., 2002; Yan and Cao, 2006), likely due to chilling injury and indicating unsuitability for cool regions. *H. chinensis* is restricted to areas below 600 m elevation in Guangxi's Shiwandashan region (Huang et al., 2008), where north tropical monsoon climate provides necessary warmth but limits distribution. Winter seed maturation exposes seeds to low temperatures, risking seedling establishment and potentially limiting natural regeneration. However, germination under moist, cool conditions also represents an adaptive strategy, allowing seeds to capitalize on precipitation events for seedling establishment.

Adequate moisture is essential for germination (Qin et al., 2020). Germination was inhibited at 10% PEG-6000, reached semi-lethal rates at 15%, and was severely suppressed at 35%, consistent with studies on *Glycyrrhiza inflata* (Shi et al., 2010), *Medicago sativa*, and *Sorghum bicolor* (Li et al., 2009). Drought stress likely inhibits protective enzyme activity and osmotic adjustment, disrupting normal metabolism (Li et al., 2013). *H. chinensis* seeds show high drought sensitivity, possibly related to their native habitat and reproductive biology. As a representative species of tropical seasonal rainforest, seeds mature during the driest season and require moist conditions for germination, potentially explaining their restriction to dense valley forests and stream banks (Huang et al., 2008).

Temperature and drought stress interactively affect germination. At 20 °C, germination duration initially increased then decreased with drought intensity, suggesting adaptive adjustment of germination timing to mitigate environmental variability and reduce mortality risk (Wang et al., 2016; Zhang et al., 2022). Under 5% PEG-6000, germination rates remained high at 20 °C (82.22%) and 25 °C (84.45%), possibly due to increased osmotic adjustment and protective enzyme activity (Mai et al., 2009; Zhang et al., 2012). Under 35% PEG-6000, germination rates at 20 °C and 25 °C were 8.89% and 15.35%, with radicle lengths of 1.63 cm and 2.04 cm, respectively, demonstrating that elevated temperature can alleviate drought inhibition (Tang and Nan, 2019). Continued radicle growth facilitates water absorption, indicating that seeds maintain viability under severe stress as an adaptive strategy (Tang and Nan, 2019). Critically, no germination occurred at 15 °C under 35% PEG-6000, revealing that combined low temperature and severe drought is lethal.

In summary, both temperature and drought stress affect *H. chinensis* germination. Fifteen degrees Celsius inhibits germination, while 20–25 °C is optimal, with 25 °C best for early seedling growth. High moisture requirements mean germination inhibition intensifies with drought stress, though 20–25 °C can mitigate inhibition under 35% PEG-6000 stress. Low temperature and drought likely constrain seedling distribution and natural regeneration. For artificial cultivation, maintain adequate moisture and use 20–25 °C to promote germination, with approximately 25 °C optimal for subsequent seedling growth.

References

CHEN SC, WANG M, WANG J, et al., 2017. Response of seed germination and seedling physiological characteristics of *Medicago sativa* to the simulated osmotic potential of PEG6000[J]. *Chinese Journal of Applied Ecology*, 28(9): 2923-2931.

FAN CZ, WU XY, GUAN X, et al., 2021. Concentration effects and its physiological mechanism of soaking seeds with brassinolide on tomato seed germination under salt stress[J]. *Acta Ecologica Sinica*, 41(5): 1857-1867.

GUANG Z, WANG LJ, DUAN L, et al., 2022. Effects of PEG simulated drought stress on seed germination of *Abutilon theophrasti* medicus[J]. *Seed*, 41(8): 66-70.

HUANG SX, CHEN H, PAN B, et al., 2008. Characteristics of *Hopea chinensis* community, an endemic and endangered species in Guangxi[J]. *Acta Botanica Boreali-Occidentalia Sinica*, 28(1): 164-170.

HUANG SX, CHEN H, TANG WX, et al., 2008. Biological and ecological characteristics of *Hopea chinensis*, a plant endemic to Guangxi[J]. *Biodiversity Science*, 16(1): 15-23.

HUANG N, LIU XS, LIAO NY, et al., 2022. Study on desiccation sensitivity of seeds of extremely endangered plant *Hopea chinensis*[J]. *Guangxi Forestry Science*, 51(5): 634-640.

LI Y, LI X, DING FB, et al., 2021. Responses of *Potentilla rupestris* seeds germination to environmental factors[J]. *Seed*, 40(4): 85-89.

LEI CY, ZHANG H, ZHANG DD, et al., 2020. Effects of temperature, salinity and light on seed germination of *Betula halophila*[J]. *Chinese Wild Plant Resources*, 39(11): 39-43.

LI DD, LI XH, LIU J, et al., 2022. Effects of single treatments of gibberellin and drought stress on seed germination of rare and endangered plant *Rhododendron xiaoxidongense*[J]. *Journal of Plant Resources and Environment*, 31(4): 57-64.

LI XS, PENG MC, DANG CL, 2007. Research progress on natural regeneration of plants[J]. *Chinese Journal of Ecology*, 26(12): 2081-2088.

LIU XS, 2019. Effects of temperature, light, and PEG on seed germination in different ecotypes of *Achnatherum inebrians*[J]. *Pratacultural Science*, 36(6): 1600-1607.

LI WR, ZHANG SQ, SHAN L, 2009. Seeds germination characteristics and drought tolerance of alfalfa and sorghum seedling under water stress[J]. *Acta Ecologica Sinica*, 29(6): 3066-3074.

LI ZP, ZHANG WH, CUI YC, 2013. Effects of PEG simulated drought stress on seed germination and growth physiology of *Quercus variabilis*[J]. *Acta Botanica Boreali-Occidentalia Sinica*, 33(10): 2043-2049.

LU QB, ZHU XZ, LIU CQ, et al., 2020. Pollination biology of *Hopea chinensis*[J]. *Guihaia*, 40(11): 1628-1637.

MAI MM, SHI DX, WANG ML, et al., 2009. Seed germination and seedling growth of *Cercidiphyllum japonicum* with PEG treatment[J]. *Scientia Silvae Sinicae*, 45(10):94-99.

MO L, TANG WX, MAO SZ, et al., 2009. Photosynthesis characteristics of rare and endangered plant *Hopea chinensis*[J]. *Journal of Fujian College of Forestry*, 29(4): 357-361.

QIN AL, GUO QS, MA FQ, et al., 2020. Effects of temperature, light and water conditions on seed germination of *Thuja sutchuenensis* Franch.[J]. *Seed*, 39(2): 15-20.

SHENG HY, GE Y, CHANG J, et al., 2004. Influence of environmental factors on seed germination of two species in Umbellaceae[J]. *Acta Ecologica Sinica*, 24(2): 221-226.

SHI W, XU HL, ZHAO XF, et al., 2010. Physiological and biochemical responses to drought stress during seed germination of *Glycyrrhiza inflata*[J]. *Acta Ecologica Sinica*, 30(8): 2112-2117.

SONG ZW, HAO LJ, HUANG ZY, et al., 2010. Effects of light and temperature on the germination of *Pugionium cornutum* (L.) Gaertn. and *Pugionium dolabratum* Maxim. seeds[J]. *Acta Ecologica Sinica*, 30(10): 2562-2568.

TANG W, NAN ZB, 2019. Effects of osmotic stress by PEG-6000 on germination of *Vicia unijuga* seeds under different temperature conditions[J]. *Pratacultural Science*, 36(5): 1323-1332.

TANG WX, MAO SZ, PAN B, et al., 2009. Spatial distribution pattern of seed rain and seed germination characteristics of endangered plant *Hopea chinensis*[J]. *Journal of Fujian College of Forestry*, 29(2): 149-154.

WANG JJ, MA AW, WANG ZG, et al., 2016. Effects of different temperature and moisture conditions on seed germination of *Festuca sinensis*[J]. *Acta Prataculturae Sinica*, 25(4): 73-80.

WU ML, ZHU J, AI XR, et al., 2020. Influences of PEG simulating drought stress on seed germination of *Metasequoia glyptostroboides* under different temperatures[J]. *Guihaia*, 40(11): 1691-1698.

WANG HH, WANG PC, ZHAO G, et al., 2016. Seed size and germination strategy of *Sophora davidii* under drought stress[J]. *Acta Ecologica Sinica*, 36(2): 335-341.

WEN B, YIN SH, LAN QY, et al., 2002. Ecological characteristics of seed germination of *Pometia tomentosa*[J]. *Guihaia*, 22(5): 408-412.

YAN XF, CAO M, 2006. Influence of light and temperature on the germination of *Shorea wantianshuea* (Dipterocarpaceae) seeds[J]. *Chinese Bulletin of Botany*, 23(6): 642-650.

YAN XF, ZHOU LB, SI BB, et al., 2016. Stress effects of simulated drought by polyethylene glycol on the germination of *Caragana korshinskii* Kom. seeds under different temperature conditions[J]. *Acta Ecologica Sinica*, 36(7): 1989-1996.

YU XJ, SHI SL, LONG RJ, et al., 2006. Research progress on effects of ecological factors on seed germination[J]. *Pratacultural Science*, 23(10): 44-49.

YU XJ, WANG YR, ZENG YJ, et al., 2004. Effects of temperature and osmotic potential on seed germination of *Cleistogenes songorica* and *Plantago lessingii*[J]. *Acta Ecologica Sinica*, 24(5): 883-887.

ZHANG JJ, CHAI SF, WEI X, et al., 2018. Germination characteristics of the seed of a rare and endangered plant, *Garcinia paucinervis*[J]. *Scientia Silvae Sinicae*, 54(4): 174-185.

ZHANG R, CHEN D, LIU H, et al., 2022. Effect of temperature and water potential on the germination of seeds from three different populations of *Bidens pilosa* as a potential Cd hyperaccumulator[J]. *BMC Plant Biology*, 22(1): 1-13.

ZHANG ZF, YOU YM, HUANG YQ, et al., 2012. Effects of drought stress on *Cyclobalanopsis glauca* seedlings under simulating karst environment condition[J]. *Acta Ecologica Sinica*, 32(20): 6318-6325.

ZHOU TJ, DENG T, TANG WX, et al., 2013. Physiological responses of seedlings of *Hopea chinensis* to PEG simulated drought stress[J]. *Hubei Agricultural Sciences*, 52(24): 6079-6083.

Note: Figure translations are in progress. See original paper for figures.