4 Discussion

The principal findings of this study regarding the establishment survival rate of *Tetrastigma hemsleyanum* can be interpreted within an ecological regulation framework integrating individual attributes, resource availability, and neighborhood pressure. Studies on forest regeneration have demonstrated that the transition from establishment to stable growth often constitutes a demographic bottleneck, where minor differences in individual traits and microhabitat conditions may be amplified into substantial variation in survival outcomes (Chang-Yang et al., 2021). In the present study, survival rate exhibited a pronounced nonlinear response to canopy closure, indicating that *T. hemsleyanum* is sensitive during the establishment stage to both excessive environmental stress and excessive resource limitation. This pattern is consistent with conclusions that niche differentiation and negative density dependence jointly shape seedling survival dynamics (Johnson et al., 2017). Therefore, the optimal canopy closure should be understood as a manageable operational range that reduces desiccation risk and temperature fluctuations while maintaining adequate photosynthetic returns and keeping understory competition at a moderate level. Long-term plot studies have further shown that habitat heterogeneity and density dependence exert persistent influences on seedling survival (Magee et al., 2020), providing theoretical support for the canopy closure range identified in this study.

From a mechanistic perspective, the unimodal response pattern observed here is consistent with classical interpretations of understory plant responses to light environments. Excessive shading may reduce net photosynthetic capacity and disrupt carbon balance, whereas excessive irradiance may increase transpiration and leaf temperature, leading to water deficit and photoinhibition risk. Moreover, changes in canopy structure influence ventilation and humidity conditions, thereby altering pathogen incidence. Research on understory vegetation as an ecological filter has indicated that shading and understory structural characteristics jointly regulate seedling growth and survival (George and Bazzaz, 1999). Multifactorial experiments have further demonstrated significant interactions among light, temperature, and understory cover, with combined effects often exhibiting nonlinear characteristics (De Lombaerde et al., 2020). Consequently, differences in survival under varying canopy closure levels observed in this study likely reflect the combined effects of light availability, water balance, and microclimatic stability rather than changes in light intensity alone.

Differences among nursery modes further highlight the importance of individual attributes during the establishment stage. A global meta-analysis has shown that initial seedling size and stress-resistance traits significantly affect post-transplant survival, with larger individuals generally exhibiting higher survival probabilities across most site conditions (Andivia et al., 2021). In restoration experiments conducted under extreme heat stress, initial seedling height explained survival variation more effectively than functional trait indicators (Gardiner et al., 2019). Additionally, life-history stage modulates the relative importance of neighborhood effects, with individual attributes and microhabitat conditions often playing a dominant role during early stages (Pu et al., 2020). These findings are consistent with the present results, indicating that root system quality and individual robustness developed during the nursery stage determine the capacity of seedlings to overcome the establishment bottleneck. Container-based nursery cultivation enhances rhizosphere conditions and preserves root integrity, thereby increasing tolerance thresholds to water fluctuations and shading stress and improving establishment stability.

In a broader comparative context, the conclusion that moderate canopy closure favors survival is largely consistent with observations from forest regeneration and restoration studies across multiple regions, although its applicability remains context-dependent. Research in northern coniferous forests has shown that overstory density and ground vegetation cover jointly determine seedling emergence and survival, and management must balance seedbed improvement with competition control (Kyrö et al., 2021). For *T. hemsleyanum*, an understory medicinal vine, the objective of establishment emphasizes stable survival and subsequent tuber development. Its sensitivity to strong irradiance and excessive moisture conditions may differ from that of typical tree regeneration. Therefore, under similar canopy closure levels, variation in soil moisture, ventilation, and understory vegetation structure among forest types may lead to different survival outcomes, representing an important source of inter-plot variability.