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Posted Date: 20 May 2026

doi: 10.20944/preprints202605.1293.v1

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Review

Advances in Understanding the Effects of pH and Water Depth on *B. schreberi* Cultivation and Implications for Artificial Propagation

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Abstract

Brasenia schreberi is a nationally protected aquatic macrophyte of substantial ecological value and economic significance, yet its wild populations have declined drastically due to habitat degradation and anthropogenic disturbances. This review systematically synthesizes research progress on the effects of water pH and depth on the growth, ecophysiology, mucilage quality, and community structure of *B. schreberi*, integrating findings from field surveys and controlled greenhouse experiments to elucidate critical ecological thresholds under combined environmental stressors. Our analysis reveals that natural *B. schreberi* populations are predominantly distributed in lentic habitats with stable water depths of 0.5-1.5 m (optimally 1.2-1.5 m) and circumneutral to weakly acidic conditions (pH 6.0-7.5). Deviations from these parameters substantially impair plant performance: when water depth exceeds 1.5 m or pH falls below 5.5, photosynthetic efficiency declines, root-to-shoot ratios increase aberrantly, and mucilage thickness decreases significantly. The synergistic critical threshold for population decline was identified at 1.1 m depth × pH 6.3. For artificial propagation, optimal cultivation strategies diverge from wild habitat preferences: maintaining pH at 7.0-7.5 (weakly alkaline) enhances mucilage polysaccharide accumulation and commercial quality, whereas a phenological stage-specific dynamic water-depth management regime ("shallow-deep-shallow-deep") maximizes vegetative propagation success and yield. This review provides a theoretical framework and parameterized technical guidance for wild population restoration, standardized cultivation, and hydrological regulation in plateau wetland ecosystems. Future research priorities should focus on elucidating the molecular mechanisms underlying pH- and depth-mediated mucilage synthesis, developing precision water quality management systems, and strengthening ex situ germplasm conservation.

Keywords: *Brasenia schreberi*; pH values; water depth; mucilage quality; wetland management

1. Introduction

Brasenia schreberi is a monotypic species of the genus *Brasenia* within the family Cabombaceae and represents the only extant relict species of this lineage. It occupies a key phylogenetic position in the evolutionary tree of angiosperms, and its unique evolutionary history makes it an important model for investigating the origin, diversification, and adaptive evolution of early angiosperms (Stone et al., 2021; Lu et al., 2023). The taxonomic status of *B. schreberi* has undergone multiple

revisions, with synonyms including *Hydropeltis purpurea* Michx., *Brasenia peltata* Pursh, and *Cabomba peltata* (Pursh) F. Muell. In current mainstream classification systems, it is consistently recognized as the type species of the genus *Brasenia* within Cabombaceae (Stone et al., 2021). This species is characterized by creeping rhizomes embedded in bottom sediments, peltate and orbicular leaves floating on the water surface, and the abaxial leaf surface densely covered with transparent mucilage. The flowers are small and purple, and the plant overwinters in the form of dormant buds (Yang et al., 2019; Xie et al., 2018; Stone et al., 2021). *B. schreberi* exhibits a high degree of ecological specialization, showing strong sensitivity to water temperature, light conditions, water quality, and sediment characteristics. It prefers clear, slow-flowing freshwater environments with neutral to slightly acidic pH, and its optimal growth temperature ranges from 20 to 30 °C. The species has relatively weak cold tolerance (Wang et al., 2025; Stone et al., 2021; Wang et al., 2000; Wersal & Madsen, 2011). Globally, *B. schreberi* shows a disjunct distribution pattern, occurring in tropical to temperate regions of Asia, North America, Australia, and Africa (Stone et al., 2021; Kim et al., 2012; Lu et al., 2023). Historically, it was widely distributed across southern China, particularly in regions such as West Lake in Hangzhou, Lichuan in Hubei, and Taihu Lake in Jiangsu (Stone et al., 2021; Mao et al., 2023; Zhu et al., 2017; Wang et al., 2000). However, due to the combined impacts of wetland reclamation, water pollution, eutrophication, overharvesting, and hydraulic engineering projects, the natural habitats of *B. schreberi* have undergone severe contraction. Its distribution has become highly fragmented, and population sizes have declined dramatically. Consequently, it has been listed as a key protected wild plant species in multiple countries (Kim et al., 2012; Wang et al., 2025; Xie et al., 2018; Yao et al., 2025).

B. schreberi possesses high edible and medicinal value and is a traditional aquatic vegetable in Asia, particularly in China. It is among the earliest recorded and most culturally significant aquatic vegetables in Chinese history, with a utilization history dating back several thousand years to the pre-Qin period. It was documented in classical texts such as *The Book of Songs* and *Songs of Chu* under names like “Mao” and “Shuikui,” where it was regarded both as a valuable food for rituals and banquets and as a representative element of the Jiangnan aquatic landscape. During the Wei and Jin dynasties, the well-known cultural allusion “thoughts of water shield and perch” (chún lú zhī sī) established *B. schreberi* as a symbolic expression of nostalgia and reclusive sentiment among scholars. From the Tang through the Qing dynasties, it was consistently regarded as a delicacy and was widely recorded in agricultural treatises, culinary texts, and classical poetry. At present, *B. schreberi* has developed into a characteristic cultivation industry in regions such as Hubei, Zhejiang, Jiangsu, and Hunan, where it is also processed into a variety of food products (Liu & Wei, 2021; Chen et al., 2020; Zhang et al., 2020). In addition to its culinary importance, *B. schreberi* has long been recognized in traditional Chinese medicine. It is described as sweet in taste and cold in nature, with functions including clearing heat, relieving thirst, strengthening the spleen and stomach, and detoxifying the body. Numerous classical materia medica texts classify it as both a food and medicinal resource, emphasizing its suitability for long-term consumption, particularly for the elderly, and highlighting its role in traditional health preservation and dietary therapy. Modern scientific studies have further confirmed that *B. schreberi* is rich in bioactive compounds such as polysaccharides and flavonoids, exhibiting antioxidant, antibacterial, and glucose metabolism-regulating properties. These findings demonstrate a continuous transition from traditional uses to modern scientific applications, underscoring its potential for both nutritional and pharmaceutical development (Li et al., 2023; Han et al., 2021; Su et al., 2025).

Given the scarcity of wild *B. schreberi* resources and its high edible and medicinal value, artificial cultivation represents the foundation for its sustainable utilization. Clarifying the environmental requirements for cultivation has therefore become a key focus in current ecological research on this species. Cultivation practices have demonstrated that water pH and depth are the primary environmental factors regulating vegetative propagation and growth in *B. schreberi*. Slightly acidic to neutral water conditions (pH 5.5–7.0) are optimal for stolon (creeping stem) propagation and seedling establishment, whereas excessively high or low pH levels inhibit root development and bud

germination. Meanwhile, water level management should follow the principle of “shallow planting followed by deeper water during growth,” as inappropriate fluctuations in water depth can significantly reduce propagation success and overall yield (Wang et al., 2000; Zhang et al., 2019; Wang et al., 2025). This review synthesizes the optimal ranges of water pH and depth for *B. schreberi* under both natural and artificial conditions, with the aim of providing a scientific basis and practical guidance for wild population conservation, habitat restoration, and efficient cultivation.

2. Effects of pH Conditions on Growth and Artificial Propagation

Soil and water pH profoundly influence plant growth, metabolism, and distribution by altering ionic speciation, nutrient availability, enzyme activity, and cell membrane stability. Excessively acidic conditions can damage root structures and induce metal toxicity, whereas overly alkaline conditions promote the precipitation of essential elements such as iron and phosphorus, leading to physiological nutrient deficiencies and inhibiting photosynthesis and reproduction. For terrestrial plants, soil pH directly regulates the solubility and uptake efficiency of essential mineral nutrients, including nitrogen, phosphorus, potassium, iron, manganese, and zinc, while also affecting soil microbial activity and the root respiratory environment. For aquatic plants, water pH not only determines the availability of photosynthetic carbon sources (CO_2 and HCO_3^-), but also modifies heavy metal toxicity, ammonia speciation, and dissolved oxygen levels, making it a key environmental factor shaping aquatic plant community composition and distribution. As an endangered aquatic plant highly sensitive to water conditions, *B. schreberi* is strongly regulated by ambient pH in terms of growth, mucilage accumulation, photosynthetic performance, and reproduction. A slightly acidic to neutral environment is essential for its survival and high productivity, whereas pH imbalance can result in poor growth, reduced mucilage production, and population decline (Wang et al., 2000; Xie et al., 2018; Wang et al., 2025; Zhang et al., 2019).

The pH of natural waters inhabited by wild *B. schreberi* is typically stable within the range of 6.0–7.5 (Table 1), which constitutes a critical condition for the completion of photosynthesis, tillering, mucilage accumulation, and natural regeneration. Once water pH deviates from the optimal range for *B. schreberi*, root absorption capacity is directly inhibited and leaf photosynthetic efficiency declines, leading to reduced plant vigor, decreased community coverage, and, in severe cases, population decline (Wang et al., 2000; Shi et al., 2024; Li & Dong, 2010; Gong et al., 2022). For example, wild populations of *B. schreberi* in North America are commonly found in lakes, peat wetlands, and slow-flowing waters with pH values ranging from 6.0 to 7.2. These habitats require high water quality and stable pH conditions, and both strongly acidic and strongly alkaline environments restrict its distribution and dispersal (Stone et al., 2021; Nazaire & Crow, 2008). Furthermore, surveys of multiple natural populations indicate that *B. schreberi* exhibits lower tolerance to alkalization than to acidification. When pH exceeds 8.0, symptoms such as leaf chlorosis, root decay, and reduced mucilage production frequently occur. This sensitivity is a major factor contributing to the gradual contraction of many wild populations under conditions of eutrophication and environmental change (Yao et al., 2025; Wang et al., 2025). Consistent evidence has also been reported in endangered populations in South Korea, where natural stands can only persist stably in weakly acidic to neutral waters (pH 5.8–7.0), and abnormal pH fluctuations exacerbate declines in genetic diversity and increase population fragmentation (Kim et al., 2012). Overall, the global distribution of wild *B. schreberi* is strongly associated with water pH, and stable, slightly acidic to neutral aquatic environments represent the fundamental requirement for its survival and reproduction.

In artificial cultivation systems, water pH not only affects the survival and growth of *B. schreberi*, but also serves as a key environmental factor regulating mucilage biosynthesis, yield formation, and commercial quality. Practical studies on *B. schreberi* production have shown that, unlike wild populations which prefer slightly acidic to neutral waters, moderately weakly alkaline conditions in cultivation are more conducive to achieving higher mucilage content and improved edible quality. For instance, long-term cultivation practices in major production areas of China, including Taihu Lake, West Lake, Lichuan (Hubei), and Shizhu (Chongqing), consistently demonstrate that,

under conditions of good water quality and suitable sediment nutrients, maintaining water pH within a slightly alkaline range of 7.0–7.5 (Table 1) can significantly enhance the secretory activity of glandular structures on the surface of young organs. This, in turn, promotes the accumulation of mucilage polysaccharides, improving the tenderness and commercial grade of young shoots. Such pH regulation has become a critical technical component in high-yield and high-quality cultivation practices (Xu & Yuan, 1992; Guo et al., 2018; Liu et al., 2019). These production experiences also indicate that excessively acidic conditions, although not immediately lethal, can suppress mucilage-related metabolic processes, resulting in thinner mucilage layers and inferior texture. Conversely, excessively high pH reduces nutrient availability, impairs root physiological function, and induces leaf chlorosis, ultimately diminishing both yield and quality. Therefore, cultivation systems typically adopt a management strategy of maintaining “neutral to slightly alkaline conditions with minimal fluctuation” (Wang et al., 2000; Zhang et al., 2015; Wu, 2009). Although the scale of *B. schreberi* cultivation outside China remains relatively limited, similar emphasis on pH regulation has been observed. In North America, large-scale cultivation systems that simulate natural habitats have shown that moderately increasing water pH to a slightly alkaline range can effectively improve the visual quality and mucilage thickness of *B. schreberi*, consistent with the cultivation strategies developed in China (Stone et al., 2021). In East Asia, intensive cultivation systems aimed at premium quality similarly maintain pH at 7.0–7.5 as an important measure to enhance mucilage production. Overall, the key difference between artificial cultivation and natural habitats lies in their functional objectives: wild *B. schreberi* prioritizes environmental adaptation and population persistence, favoring slightly acidic to neutral waters, whereas cultivation systems aim for high yield, superior quality, and elevated mucilage content by adjusting water pH to slightly alkaline levels. This differential pH response highlights the physiological plasticity of *B. schreberi* and provides important theoretical and practical guidance for wild population restoration, wetland rehabilitation, and efficient cultivation practices.

Table 1. Comparison of pH values and growth types of water shield sampling sites at home and abroad.

Country/Region	Province/Area	Specific Sampling Site	pH Range	Growth Type	Reference
China	Jiangsu	Taihu Lake, Jiangsu	5.5–6.5	Cultivated	Xu & Yuan, 1992
		Suzhou Vegetable Research Institute, Jiangsu	6.5–7.0	Cultivated	Guo et al., 2018
		Main production area in Lichuan	6.0–7.0	Cultivated	Mao et al., 2023
	Hubei	Fubaoshan Brasenia cultivation base, Lichuan	5.5–6.5	Cultivated	Wu, 2009
		Mangshan Brasenia population area	6.34 ± 0.24	Wild	Zhou, 2023
	Hunan	Wuling Mountain region	6.0–7.0	Wild	Shi et al., 2024
		Langpan Lake, Mangshan National Nature Reserve	4.27 ± 0.80	Wild	Zhou, 2023
	Sichuan	Mahu Lake area, Leibo County	6.0–7.0	Wild	Wang et al., 2000
	Yunnan	Beihai Wetland, Tengchong	6.6	Wild	Sun et al., 2021
	Overseas	USA	Wetland wild populations, California	6.0–7.2	Wild
Artificial cultivation area, New Hampshire			6.0–7.0	Cultivated	Nazaire & Crow, 2008

South Korea	Artificial cultivation area, New Hampshire	5.8–7.0	Wild	Kim et al., 2012
	Small-scale cultivation sites	6.0–6.5	Cultivated	Kim et al., 2012

3. Effects of Water Depth on Growth and Artificial Propagation

Water depth is one of the core environmental factors influencing the growth and development of aquatic plants. It directly impacts light acquisition, gas exchange, nutrient absorption, and available living space for plants. Both excessively high and low water depths can significantly disrupt normal plant growth (Zhang et al., 2019; Dong et al., 2018; Zhu et al., 2022). When water depth is too shallow, the thermal stability of the water body is poor, and large diurnal temperature fluctuations occur. Plant leaves are more prone to exposure to air, suffering from high temperatures and intense sunlight, which may cause sunburn. Additionally, insufficient water levels and anoxic sediment conditions can stunt root development, weakening plant growth and reducing stress resistance. Conversely, when water depth is too deep, light intensity decreases significantly with increased water depth, limiting normal photosynthesis and resulting in insufficient accumulation of photosynthetic products. Increased water pressure also inhibits stem and leaf extension, reducing gas exchange efficiency. In severe cases, plants may experience excessive elongation, rot, or even death (Xie et al., 2018; Zhuang, 2017; Shi et al., 2024). Moreover, abnormal water depth can indirectly influence other environmental factors such as water pH, dissolved oxygen, and nutrient concentration, further exacerbating the negative impact on aquatic plant growth (Wang et al., 2000; Gong et al., 2022).

As a typical perennial aquatic floating-leaved plant, *B. schreberi* exhibits a clear adaptive range for water depth, a feature confirmed by both domestic and international research (Stone et al., 2021; Kim et al., 2012; Chen et al., 2024). *B. schreberi* thrives in water depths of 1.2–1.5 meters, where it can receive sufficient light for photosynthesis, ensuring the stable accumulation of photosynthetic products. In this range, the stems and leaves extend smoothly to the water surface, facilitating gas exchange and nutrient absorption, which promotes root development and robust stem and leaf growth, laying the foundation for mucilage accumulation and yield formation (Liu et al., 2019; Guo et al., 2018; Zhang, 2018; Wu, 2009). When water depth is too shallow (<0.5 m), leaves are vulnerable to heat damage, and root development is poor. This is manifested by yellowing leaves with scorched edges, short roots, and reduced root hairs. Additionally, high sediment temperatures increase the risk of pathogenic microbial growth, raising the likelihood of diseases like leaf rot, which further inhibits *B. schreberi* growth and mucilage synthesis (Wang et al., 2023; Zhang et al., 2015; Li et al., 2009). Conversely, when water depth exceeds 2.0 meters, insufficient light inhibits growth, leading to excessive stem elongation, thin leaves, significantly reduced photosynthetic efficiency, and decreased mucilage content. In severe cases, plants may topple or rot (Zhang et al., 2019; Zhou, 2023; Li et al., 2024). However, *B. schreberi* demonstrates strong adaptability to water level fluctuations. It can grow normally within a water depth variation of 0.5–2 meters, a trait that allows it to cope with seasonal water level changes due to precipitation and maintain population stability (Zhuang, 2017; Wei et al., 2022; Zhang & Gao, 2008). In domestic wild populations in areas such as Lichuan (Hubei), the highlands of Xiangnan (Hunan), and West Lake (Hangzhou), the natural water depth typically stabilizes between 0.5 and 1.5 meters. Populations at water depths of 1.2–1.5 meters exhibit the highest coverage and growth rates (Shi et al., 2024; Li & Dong, 2010; Gong et al., 2022). In North America, wild *B. schreberi* populations are commonly found in lakes, peat wetlands, and slow-flowing waters with depths ranging from 0.3 to 1.5 meters. Similarly, endangered *B. schreberi* populations in South Korea generally occur at depths of 0.5–1.2 meters, reflecting the plant's preference for shallow to medium depths (Stone et al., 2021; Kim et al., 2012, 1996; Nazaire & Crow, 2008).

Under artificial cultivation conditions, regulating water depth within the optimal range can significantly enhance the yield and quality of *B. schreberi*. This technique has become a key component in high-quality, high-yield cultivation in major production areas such as Taihu Lake and Lichuan (Xu

& Yuan, 1992; Liu et al., 2019; Zhu et al., 2017). The water depth requirements for *B. schreberi* at different developmental stages vary (Table 2), and this variation is an important characteristic for environmental adaptation, ensuring the successful completion of its life cycle (Wei et al., 2022; Li et al., 2013; Xu et al., 2000). In artificial cultivation, water depth control for stem cutting asexual reproduction needs to align closely with its growth and development patterns, following the core principle of "shallow—deep—shallow—deep," which adapts flexibly to the water depth needs of different natural growth stages. Specifically, during the planting and initial growth period (germination stage), a shallow water layer of 10–30 cm is maintained in the field to facilitate root development and survival of the seed stems. After seedling emergence, the water level is increased to 30–40 cm to provide a suitable environment for seedling growth. In summer, during the vigorous growth phase, the water depth is gradually increased to 50–100 cm to meet the increased lighting and space requirements as growth accelerates. As autumn approaches, the water level is lowered to 30–40 cm to adapt to the changing growth rhythm of the plants. During the winter dormancy period, the water depth is appropriately raised to 50–60 cm for frost protection, ensuring the safety of winter buds for overwintering. Research on different water depth cultivation experiments for *B. schreberi* has found that excessive water depth leads to thick stems with few leaves, while shallow water causes thin stems with many leaves. The most suitable water depth during the growing season is between 60–80 cm, where the seed stems are of optimal length and thickness, and the highest number of healthy seedlings are produced. In conclusion, water depth regulation at different developmental stages—whether for natural growth or artificial asexual reproduction—must be adjusted flexibly according to local climate, water quality, and cultivation models. This is one of the key technologies for achieving high-quality and high-yield *B. schreberi* cultivation (Wu, 2009; Li et al., 2009; Guo et al., 2018).

Table 2. Planting indicators and water depth conditions for stem and segment cutting propagation of water shield.

Planting Time	Pre-Planting and Post-Planting Water Depth (cm)	Post-Germination Water Depth (cm)	Summer Water Depth (cm)	Autumn Water Depth (cm)	Winter Water Depth (cm)	Reference
Around Qingming	20	25	30~40		20~30	Li Dong, 2018.
March–April	15~20		50~60		30~40	Wang Miaomiao et al., 2018.
Late March		30	50~80	30	50~60	Zhang Lei et al., 2015.
Mid–Late April	10~20	30~40	60~80	30~40	30	Zhong Falin et al., 2012.
Spring	20~30		60~70	80~90	50~60	Liu Yuping et al., 2009.
March–April	10~20	30~40	60~100	30~40	60	Shen Min & Huang Bingyuan, 2006.
Early–Mid March		30	50~60	30	50~60	Liu Yiman, 1997.
Early–Mid April	30	40~50	80~100	40~50	50~60	Xu Hongcai, 1997.
April–May	5~10	30	80~100	60	50~60	Xiong Miaoguang.

4. Synergistic Effects of Water Depth and pH on the Growth of *B. schreberi*

B. schreberi is a typical perennial aquatic floating-leaved plant that exhibits significant ecological responses to both water depth and pH conditions. These two environmental factors also show marked synergistic effects on the plant's growth and development, jointly constituting key

environmental determinants that influence its yield and quality (Zhang et al., 2019; Shi et al., 2024; Gong et al., 2022). A study conducted in Langpan Lake, Mangshan, Hunan, which involved continuous sampling over 12 months, revealed that when the water depth was 0.9 m and pH was 4.5, the mucilage thickness was 34% lower than the predicted value for either factor alone. This was the first report of the combined negative effects of acidification and deep water at the field level (Zhou, 2023; Li et al., 2024). In a study of 12 lakes along the Uruguay-Brazil border, a Generalized Additive Model (GAM) was used to incorporate both "maximum water depth" and "pH" as smooth terms. By applying tensor product smoothing, a continuous surface was created to show the probability of occurrence as these two factors changed. The study first identified the critical zone of "1.1 m × pH 6.3", providing a model framework for determining interaction thresholds in future studies (Bonilla et al., 2021). In greenhouse-controlled experiments on *B. schreberi*, when pH was 5 and water depth was 1.2 m, total biomass decreased by 38%, whereas the combination of pH 7 and water depth of 1.2 m resulted in only a 9% decrease. This indicates that at lower pH, the free CO₂ and bicarbonate concentrations in the water decrease simultaneously, forcing the plant to activate high-energy carbon concentration pathways, which amplifies the stress effect from deep water (Wersal & Madsen, 2011; Xie et al., 2018). Another study on three aquatic plant species, including *B. schreberi*, found that when pH was 5.5 and water depth was 0.9 m, root zone O₂ decreased by 37%, Al³⁺ activity increased, and the root-to-shoot ratio increased by 35%. This suggests that both acidification and deep water co-inhibit root conductivity and oxygen environment (Chadwell & Engelhardt, 2002; Zhuang, 2017). Under optimal water depth conditions (1.2–1.5 m) and the most suitable pH range (5.5–6.5), *B. schreberi* forms a well-developed root system and lush foliage, with yields reaching 3000–4000 kg/acre and mucilage content up to 4.2%, achieving dual optimization of both yield and quality (Liu et al., 2019; Guo et al., 2018; Wu, 2009). When the water depth is too shallow (<0.8 m) and pH is too high (>7.0), the combined effects of heat and alkalinity stress significantly reduce the plant's heat resistance and nutrient absorption capacity, leading to inhibited growth and accelerated leaf aging (Zhang et al., 2015; Wang et al., 2000). Conversely, when the water depth is suitable but pH is too low (<5.0), although the depth provides good physical support, the acidic environment limits the biological availability of essential nutrients like nitrogen and phosphorus, thus restricting yield formation (Gong et al., 2022; Yao et al., 2025; Wang et al., 2025). Therefore, in practical cultivation management, it is important to optimize the synergistic effects of water depth and water quality regulation. By stabilizing water depth within the range of 1.2–1.5 m and maintaining pH between 5.5 and 6.5, the positive synergistic effects of these two factors can be maximized, promoting high-quality and high-yield cultivation of *B. schreberi* (Xu & Yuan, 1992; Li & Dong, 2010; Chen et al., 2024).

Table 3. Interactive effects of water depth and pH on key traits of *B. schreberi* under combined stress.

Study Site/Experiment System	Water Depth (m)	pH Range	Response Variable	Main Interaction Effect	Statistics	Reference
Langpan Lake, Mangshan, Hunan (field)	0.2–0.9	4.3–6.3	Mucilage thickness	34% reduction at 0.9 m × pH 4.5	F = 11.3, p < 0.01	Reference
12 lakes, Uruguay–Brazil border (field)	0–2.0	6.0–7.9	Occurrence probability	Sharp decline at 1.1 m × pH 6.3	GAM interaction term: 42%	Bonilla et al., 2012
Louisiana State University greenhouse experiment (USA)	0.3, 0.6, 1.2	5, 7, 9	Total biomass	38% decrease at pH 5 × 1.2 m	F = 6.42, p = 0.02	Wersal & Madsen, 2011

Freshwater wetlands and reservoir systems, Maryland (lab + field)	0.3、0.9	5.5、7.0、8.5	Root-to-shoot ratio	35% increase at pH 5.5 × 0.9 m	Not reported	Chadwell&Engelhardt, 2002
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5. Conservation and Management Strategies and Future Perspectives for *B. schreberi*

As a nationally protected Class II wild plant, the long-term persistence of wild populations of *B. schreberi* and the achievement of high-quality, high-yield production in artificial cultivation both depend strongly on suitable aquatic environmental conditions. Among these, water pH and depth are the primary regulatory factors. Integrating standardized management of nature reserves with refined regulation in cultivation systems is therefore essential for achieving the coordinated development of conservation and utilization (Stone et al., 2021; Wang et al., 2000; Zhu et al., 2022).

Under natural conditions, wild populations of *B. schreberi* are best adapted to pH values of 5.8–7.5 (slightly acidic to neutral) and water depths of 0.5–1.5 m, with 1.2–1.5 m being optimal for growth. Accordingly, conservation and management efforts should rely on protected areas within natural distribution regions to establish long-term monitoring systems for pH and water depth. When pH deviates from the optimal range, mild adjustments using lime or organic matter (e.g., humic substances) should be applied. If water depth falls below 0.5 m, water supplementation through irrigation is required, whereas depths exceeding 2.0 m should be reduced via drainage. In addition, strict control of wastewater discharge and overharvesting is necessary to maintain water quality and ecosystem stability.

In artificial cultivation, to enhance mucilage content and overall product quality, pH should be maintained within a slightly alkaline range of 7.0–7.5, while water depth should generally be kept below 1.0 m. Close monitoring of plant growth status—including leaf morphology, root development, and tillering—is essential. Symptoms such as chlorosis or root decay should be addressed promptly through environmental adjustments. When pH exceeds 8.0 or water depth remains below 1.0 m for prolonged periods, corrective measures must be implemented. Ecological cultivation models, such as those developed in Lichuan, may serve as useful references for balancing plant growth and mucilage quality.

Looking forward, the conservation and utilization of *B. schreberi* should follow the principle of “ecological priority with technological support.” On the conservation side, monitoring and management systems within protected areas should be further improved, with the integration of digital technologies to enable precise regulation of pH and water depth, alongside strengthened conservation of wild germplasm resources and research on genetic diversity. On the cultivation side, further investigation into the mechanisms by which pH and water depth influence mucilage biosynthesis is needed, along with the development of improved cultivars and standardized management practices. At the same time, promoting the integration of industry, academia, and research will facilitate value-added processing and agro-ecotourism, ultimately achieving a synergistic balance between conservation and sustainable industry development.

Author: contributions: Mei Sun designed the content and structure of this review and was primarily responsible for its revision; Xinyu Wang was the main author of this review; Congli Xu, Bianling Zhu, and Yue Zhao participated in writing and revising parts of this review; Qiuling Sun, Qibin Liang, and Jie Zhou participated in revising this review.

Funding: This study was supported by the Gaoligong Mountain Ecological Function Enhancement and Sustainable Development Technology Research and Demonstration Project-Gaoligong Mountain Conservation Capacity Improvement Sub-project (202303AC10001204); the “Xingdian Talent” Youth Talent Project of Yunnan

Province, China (XDYCQNRC-2023-0218), and the Yunnan Biodiversity Conservation Foundation Project, China.

Data availability: The data that support the findings of this study are available from the corresponding author upon reasonable request. Please contact the author at sm0510215@163.com.

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Competing interests: The authors declare that they have no competing interests.

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