

Article

The Effect of Light on Plant Growth and Physiology of *Acmella radicans* and *A. paniculata* in China

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Abstract

Acmella radicans (Jacquin) R.K.Jansen is an annual herb native to Central America. In China, it is becoming increasingly invasive and often co-occurs with the native congener *A. paniculata* (Wall. ex DC.) R.K.Jansen in some habitats. In order to understand the invasion mechanism of *A. radicans*, we investigated the growth parameters of both the invasive *A. radicans* and the native congener, *A. paniculata*, under different light conditions (5%, 25%, 50%, 75%, and 100% of light availability) using potted plants in a glasshouse. Light level, plant species, and their interaction were significant, with plant species generally having a greater effect than light level. *Acmella radicans* and *A. paniculata* showed great phenotypic plasticity to various light intensities and had a similar trend with increased shade. The plasticity indices of all parameters of *A. radicans*, except for branch length and inflorescence number, were greater than those of *A. paniculata* under the same light intensity. The physiological parameters for *A. radicans* under both favorable (high light intensity) and unfavorable (low light intensity) conditions showed less inhibition than those of *A. paniculata*. All these responses indicated that *A. radicans* had greater phenotypic plasticity and higher adaptability to low light, which may contribute to its invasion success.

Keywords: native congener; phenotypic plasticity; light intensity; invasion mechanism



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1. Introduction

Biological invasions have become increasingly common with increasing globalization of the world economy and have emerged as a major global concern [1–3]. Invasive alien species can cause significant social, economic, and environmental problems by reducing

productivity and affecting ecosystem structure and function [4–6]. The invasion of an exotic species is mainly dependent on its own invasiveness and the invasibility of particular environments [7–9]. The invasion process of an exotic species often involves a series of complex processes, such as transport, introduction, establishment, and spread of the species [10]. Thus, the probability of an alien species becoming a harmful invasive species tends to be low [11]. Consequently, determining the factors and biological characteristics that facilitate the invasion of invasive species has become one of the priorities of research worldwide.

Invasive alien plants typically possess biological and ecological characteristics that give them inherent advantages over native plant species [12,13]. They also often have a higher tolerance to various abiotic environmental factors than native congeners [14,15]. Among the conditions affecting growth, the amount of available light is one of the most critical abiotic factors [16,17]. Compared to native species, invasive alien plants tend to be better competitors for light and/or exhibit comparatively higher shade tolerances through responding at various scales ranging from the cellular level to the whole plant [15,18,19]. Hence, research on how invasive and native congeners occupying similar niches respond under different light conditions is an important avenue for exploring plant invasion mechanisms [20,21].

The annual herb *Acmella radicans* (Jacquin) R.K.Jansen (Asteraceae) originates in Central America and has successfully invaded many countries and regions worldwide [22–25]. In China, *A. radicans* is found widely in southern regions of Yunnan Province and is now considered as a serious invasive species, infesting a diverse range of agricultural and non-agricultural habitats with high rates of disturbance [6,26]. The invasion of *A. radicans* has caused severe negative impacts to crop production, biodiversity, structure, function, and soil nutrients of invaded ecosystems, through strong competitiveness, a large long-term soil seedbank, a broad seed germination niche, and a high ability to release allelochemicals [6,26–28].

To better understand mechanisms of invasiveness, it is useful to compare the ecophysiology of invasive plants with that of native plants, and, in particular, it is useful to do pairwise comparisons between plant species in the same genus [29]. *Acmella paniculata* (Wall. ex DC.) R.K.Jansen, is an indigenous and traditional Chinese medicinal plant, and is a native congener of *A. radicans* [30]. This species is generally found in freshwater habitats, paddy, and sugar cane fields, as well as waste wetlands [31]. In Yunnan Province, *A. radicans* generally has a wider distribution and causes greater negative impacts than *A. paniculata* when they co-occur in similar environments [6]. In an earlier study, *A. radicans* was found to grow in a wide range of environmental conditions, including light and moisture [32]. However, this study was limited in that it focused solely on *A. radicans* without comparing these physiological traits with other plant species.

The overall objectives of the current study are to determine effects of light intensity on the growth, biomass, morphology, physiology, and plant nutrients of *A. radicans* and its native congener *A. paniculata* to assess ecophysiological differences between the two species. This comparison is to highlight what traits of *A. radicans* comprise the mechanism by which it behaves as an invasive species. Our hypothesis is that the invasive plant *A. radicans* would exhibit greater adaptability to varying light intensity, enabling it to grow more rapidly under a greater variety of light intensities than its congener *A. paniculata*. Greater knowledge of the invasive mechanism employed by *A. radicans* should provide helpful insights into its management.

2. Methods

2.1. Study Species

Mature seeds of *A. radicans* and *A. paniculata* were collected separately from numerous plants of the same populations within cultivated lands in Bangbing Township (23°33' N,

99°77' E), Shuangjiang County of Yunnan Province in December 2023. Seeds were taken to the laboratory at the Agricultural Environment and Resource Research Institute, Yunnan Academy of Agricultural Sciences, China, in paper bags, dried at room temperature for three weeks and then stored in the refrigerator at -4°C .

2.2. Experiment Design and Data Collection

The study was conducted from June to December in 2024 in the greenhouse of Yunnan Academy of Agricultural Sciences, Songming County ($25^{\circ}35' \text{ N}$, $103^{\circ}11' \text{ E}$), Yunnan Province, China. On 25 June 2024, fully developed *A. radicans* and *A. paniculata* were sown separately in seedbeds in the greenhouse. After six weeks, two seedlings of similar size of each species were transplanted separately into each pot (20 cm diameter and 25 cm deep), filled with soil collected from bare ground in the glasshouse, such that each pot had two similar-sized seedlings of the same species. The soil had a pH of 6.80 ± 0.11 , an organic matter content of $27.58 \pm 0.39 \text{ g}\cdot\text{kg}^{-1}$, available N $86.76 \pm 1.35 \text{ mg}\cdot\text{kg}^{-1}$, available P $32.01 \pm 1.12 \text{ mg}\cdot\text{kg}^{-1}$, and available K $190.06 \pm 8.16 \text{ mg}\cdot\text{kg}^{-1}$. A total of 200 pots of each species were set up. The seedlings were maintained under optimal growing conditions.

After 25 days, seedlings were of suitable size (about 7 cm high, with five fully expanded leaves) and the experiments commenced, using a completely randomized design with different light levels. Within the glasshouse, different light levels were obtained within $5 \text{ m} \times 4 \text{ m} \times 1.5 \text{ m}$ black nylon shade sheds with different shade ratings: non-irradiance (NI) treatment received 5%, the low-irradiance (LI) treatment received 25%, the medium-irradiance (MI) treatment received 50%, the high-irradiance treatment (HI) received 75%, and the full-irradiance treatments (FI) received 100%. Twenty shade sheds were constructed for each, and each shed was separated by 2.5 m distance. Each shed contained eight pots randomly selected of one or the other species. There were 5 light treatments $\times$ 4 replicate sheds $\times$ 8 pots $\times$ 2 species = 320 total pots, with the full irradiance acting as the control treatment. During the experiment, sufficient water was provided to each plant equally, and the pots were weeded by hand. No synthetic fertilizers were applied to any pot.

On 15 November 2024, the net photosynthetic rate (Pn) of leaves of individual plants of each of *A. radicans* and *A. paniculata* from each pot was measured with a Portable Photosynthesis System (LI-COR Biosciences LI6400XT, Lincoln, NE, USA). On 28 December 2024, all plants were harvested and the plant height, branch length (total branch length not including the main stem), basal stem diameter, petiole length, leaf area (all leaves) (Li-3000A; LI-COR Biosciences, Lincoln, NE, USA), inflorescence number, seed number, and biomass (dried weight) of each species were recorded. The chlorophyll content of fresh leaves and plant nutrients from whole plants were analyzed.

2.3. Statistical Analysis

The normality and homogeneity of variances were tested, and log transformations of the data were performed to correct deviation before analysis, if necessary. A two-way ANOVA using General Linear Models (GLMs) (IBM SPSS 26.0, Armonk, NY, USA) was used to test the effect of plant species, light intensity and their interactions on the morphological and physiological characteristics, and plant nutrient composition of *A. radicans* and *A. paniculata*. The inhibitory rate for plant morphological, physiological, and plant nutrient characteristics was calculated using the formula $(C - T)/C \times 100\%$, where C is the mean value of FI, and T is the mean value of each shade treatment; IR N 0 shows inhibition, IR b 0 shows promotion, and the magnitude of IR values reflects the intensity of the shade effect. The F, P, and R^2 statistics were calculated, considering plant species and light levels, with their interaction as factors (5% significance level) (ns, *, and ** indicate $p > 0.05$, $p \leq 0.05$, and $p \leq 0.01$, respectively). Tukey's honestly significant difference (HSD),

post hoc multiple comparisons, and homogeneity of variance tests were explored to detect significant differences among light level treatments.

3. Results

3.1. Effects of Species and Light on Plant Growth Parameters of *Acmella radicans* and *Acmella paniculata*

Plant species, light level, and their interaction had significant effects on all plant parameters tested for *A. radicans* and *A. paniculata* (Table 1). Plant species had a greater effect than light intensity on all morphological and physiological characteristics tested except for inflorescence number, seed number, Pn, and K content of the two species (Table 1).

Table 1. Two-way ANOVA results of effects of light intensity, species, and their interaction on plant growth.

Variables	Light Level		Species Level		Interaction		R ²
	F	P	F	P	F	P	
Plant height (cm)	83.754	0.000 **	88.265	0.000 **	15.788	0.000 **	0.924
Total branch length (cm)	633.279	0.000 **	5205.421	0.000 **	54.751	0.000 **	0.995
Basal stem diameter (cm)	1477.864	0.000 **	33,380.358	0.000 **	263.964	0.000 **	0.999
Petiole length (cm)	848.313	0.000 **	54,219.081	0.000 **	141.325	0.000 **	0.999
Leaf area (cm ²)	160.404	0.000 **	37,502.783	0.000 **	87.097	0.000 **	0.999
Inflorescence number	4768.768	0.000 **	88.362	0.000 **	4.164	0.008 **	0.998
Seed number	3703.523	0.000 **	30.056	0.000 **	4.443	0.006 **	0.997
Leaf biomass (g)	481.500	0.000 **	4755.738	0.000 **	40.315	0.000 **	0.994
Stem biomass (g)	7586.821	0.000 **	10,591.593	0.000 **	138.208	0.000 **	0.999
Root biomass (g)	4067.349	0.000 **	4430.265	0.000 **	89.487	0.000 **	0.998
Inflorescence biomass (g)	4617.140	0.000 **	15,309.559	0.000 **	765.470	0.000 **	0.999
Aboveground biomass (g)	5068.145	0.000 **	18,899.377	0.000 **	126.776	0.000 **	0.999
Total biomass (g)	12,130.486	0.000 **	38,158.387	0.000 **	279.547	0.000 **	1.000
Pn (μmol CO ₂ m ⁻² s ⁻¹)	2872.480	0.000 **	1967.314	0.000 **	92.582	0.000 **	0.997
Chlorophyll a (mg/g)	7903.666	0.000 **	18,693.343	0.000 **	944.941	0.000 **	0.999
Chlorophyll b (mg/g)	5272.171	0.000 **	25,145.655	0.000 **	557.258	0.000 **	0.999
N content (mg/kg)	2900.520	0.000 **	12,203.728	0.000 **	302.579	0.000 **	0.998
P content (mg/kg)	630.345	0.000 **	778.725	0.000 **	66.512	0.000 **	0.989
K content (mg/kg)	31,696.913	0.000 **	7340.116	0.000 **	1002.527	0.000 **	1.000

** indicate $p > 0.05$, $p \leq 0.05$, and $p \leq 0.01$, respectively.

3.2. Effect of Light on Plant Growth of *Acmella radicans* and *Acmella paniculata*

Plant height, total branch length, and basal stem diameter of *A. radicans* and *A. paniculata* were significantly affected by light level (Figure 1A–C). Plant height and basal stem diameter of *A. radicans* were greater than those of *A. paniculata*, but its total branch length was less than *A. paniculata*. Plant height and total branch length of both species increased significantly with decreasing light intensity (Figure 1A,B), while basal stem diameter was clearly reduced (Figure 1C). Inhibition of most characteristics of *A. radicans* was less than that of *A. paniculata* under same light conditions (Table 2).

The petiole length and leaf area were much larger in *A. radicans* than in *A. paniculata* (Figure 1D,E). Petiole length and leaf area of both species increased significantly with a decrease in light intensity, usually with less inhibition for *A. radicans* than for *A. paniculata* (Table 1). *Acmella radicans* produced a greater seed number while *A. paniculata* produced a greater inflorescence number. Both inflorescence and seed number of *A. radicans* and *A. paniculata* were greatest at high irradiance and then were markedly reduced with decreasing light intensity (Figure 1F,G), generally with less inhibition for *A. radicans* than for *A. paniculata* (Table 2).

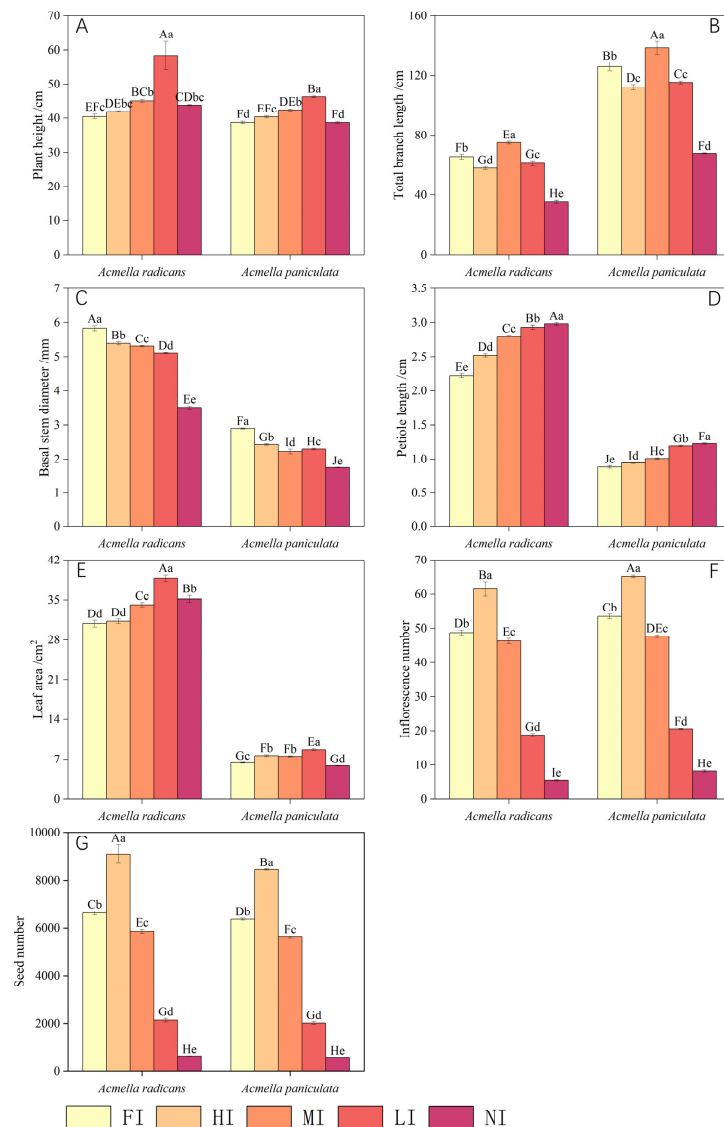


Figure 1. Plant growth and reproductive characteristics of *Acmedla radicans* and *Acmedla paniculata* under different light levels [FI = full irradiance (100%), HI = high irradiance (75%), MI = moderate irradiance (50%), LI = low irradiance (25%), NI = non irradiance (5%)] for (A) plant height, (B) total branch length, (C) basal stem diameter, (D) petiole length, (E) leaf area, (F) inflorescence number, and (G) seed number. Different small and capital letters above bars indicate a significant difference at 0.05 level for one species and between two species under different treatments, respectively.

Table 2. Inhibitory rate (%) of shade rate on plant growth and physiological characteristics of *Acmedla radicans* and *Acmedla paniculata*.

Variables	HI		MI		LI		NI	
	<i>Acmedla radicans</i>	<i>Acmedla paniculata</i>	<i>Acmedla radicans</i>	<i>Acmedla paniculata</i>	<i>Acmedla radicans</i>	<i>Acmedla paniculata</i>	<i>Acmedla radicans</i>	<i>Acmedla paniculata</i>
Plant height	−3.58	−4.26	−11.38	−9.53	−44.11	−19.41	−8.30	0.07
Total branch length	11.72	10.98	−14.18	−9.91	6.74	8.30	45.84	46.03
Basal stem diameter	7.67	16.31	9.08	23.30	12.38	20.88	39.80	39.60
Petiole length	−13.50	−7.08	−25.97	−14.16	−31.83	−34.84	−34.08	−38.81
Leaf area	−1.32	−19.58	−10.78	−17.78	−25.99	−36.08	−14.09	8.46
Inflorescence number	−26.24	−22.04	4.96	10.83	61.54	61.52	88.55	84.75
Seed number	−37.16	−32.70	11.56	11.75	67.78	68.36	90.31	90.75
Leaf biomass	−15.00	−8.73	−42.73	−25.40	−12.73	25.40	22.27	61.11
Stem biomass	−27.82	−14.15	−50.57	−44.40	−41.41	−27.91	18.49	33.40
Inflorescence biomass	20.34	22.02	27.21	29.76	49.26	51.79	86.27	88.69

Table 2. Cont.

Variables	HI		MI		LI		NI	
	<i>Acmella radicans</i>	<i>Acmella paniculata</i>	<i>Acmella radicans</i>	<i>Acmella paniculata</i>	<i>Acmella radicans</i>	<i>Acmella paniculata</i>	<i>Acmella radicans</i>	<i>Acmella paniculata</i>
Root biomass	9.49	13.14	26.49	27.88	43.49	46.79	73.51	80.77
Aboveground biomass	−9.69	−5.73	−23.57	−25.90	−6.46	−2.86	41.49	49.32
Total biomass	−4.55	−0.45	−10.17	−10.85	6.91	11.03	50.06	58.12
Pn	−12.18	−3.86	−4.69	−3.19	−1.15	0.07	15.65	23.05
Chlorophyll a	−193.03	−142.59	−266.06	−163.12	−264.24	−160.46	−225.76	−141.83
Chlorophyll b	−145.67	−142.01	−161.33	−157.99	−161.33	−157.99	−147.00	−104.14
N content	−32.86	−41.99	−47.69	−42.91	−82.22	−79.14	−74.63	−48.44
P content	−68.09	−28.45	−62.68	−43.99	−35.33	−17.60	−23.65	−6.74
K content	−19.38	−11.61	−20.87	−12.63	−68.45	−38.66	−100.70	−80.28

Abbreviations: HI = high irradiance (75%), MI = moderate irradiance (50%), LI = low irradiance (25%), and NI = non irradiance (5%).

The leaf, stem, inflorescence, root, aboveground, and total biomass of *A. radicans* were obviously greater than those of *A. paniculata* under the same light conditions (Figure 2). With a decline in light intensity, the inflorescence and root biomass of both species were significantly reduced (Figure 2C,D), whereas the leaf, stem, and total biomass were obviously increased (Figure 2A,B,E,F), usually with less inhibition for *A. radicans* than for *A. paniculata* (Table 2).

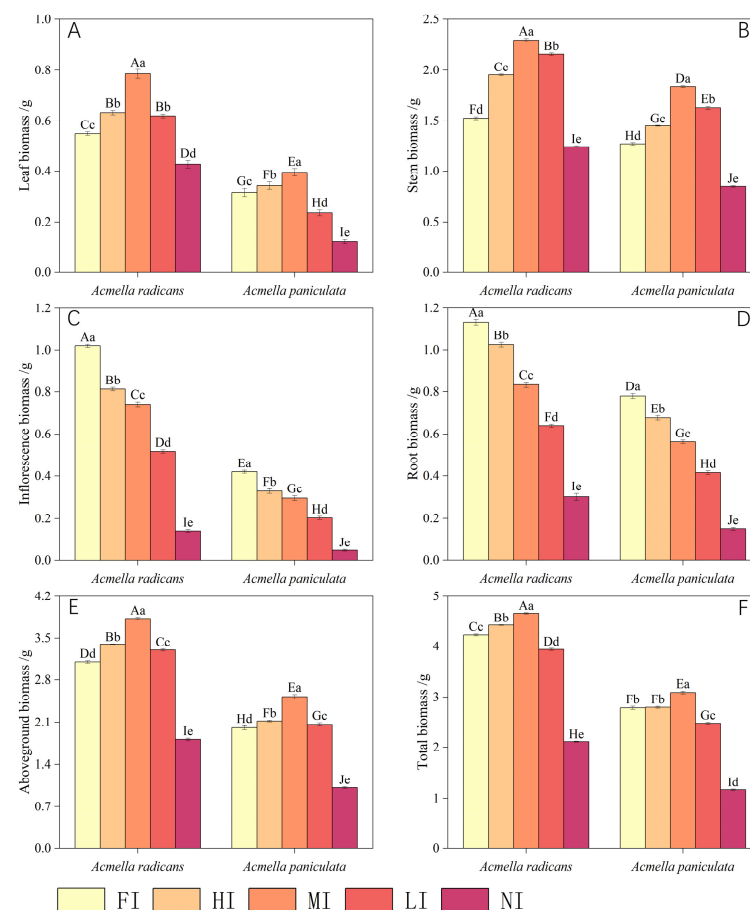


Figure 2. Plant biomass of *Acemella radicans* and *Acemella paniculata* under different light levels [FI = full irradiance (100%), HI = high irradiance (75%), MI = moderate irradiance (50%), LI = low irradiance (25%), NI = non irradiance (5%)] for (A) leaf biomass, (B) stem biomass, (C) inflorescence biomass, (D) root biomass, (E) aboveground biomass, and (F) total biomass. Different small and capital letters above bars indicate a significant difference at 0.05 level for one species and between two species under different treatments, respectively.

3.3. Effect of Light on Physiological Parameters of *Acmella radicans* and *Acmella paniculata*

Pn, chlorophyll a, and chlorophyll b content of *A. radicans* were much higher than for *A. paniculata* (Figure 3A–C). The Pn of both species was usually greater at higher light intensities but was less at the lowest light intensity (Figure 3A). The chlorophyll levels of *A. radicans* and *A. paniculata* at full irradiance were reduced by more 50% compared to other light intensities. Pn, chlorophyll a, and chlorophyll b content of both *A. radicans* and *A. paniculata* were initially noticeably increased with decreasing light intensity, and then markedly reduced, with less inhibition observed for *A. radicans* than for *A. paniculata* (Table 2).

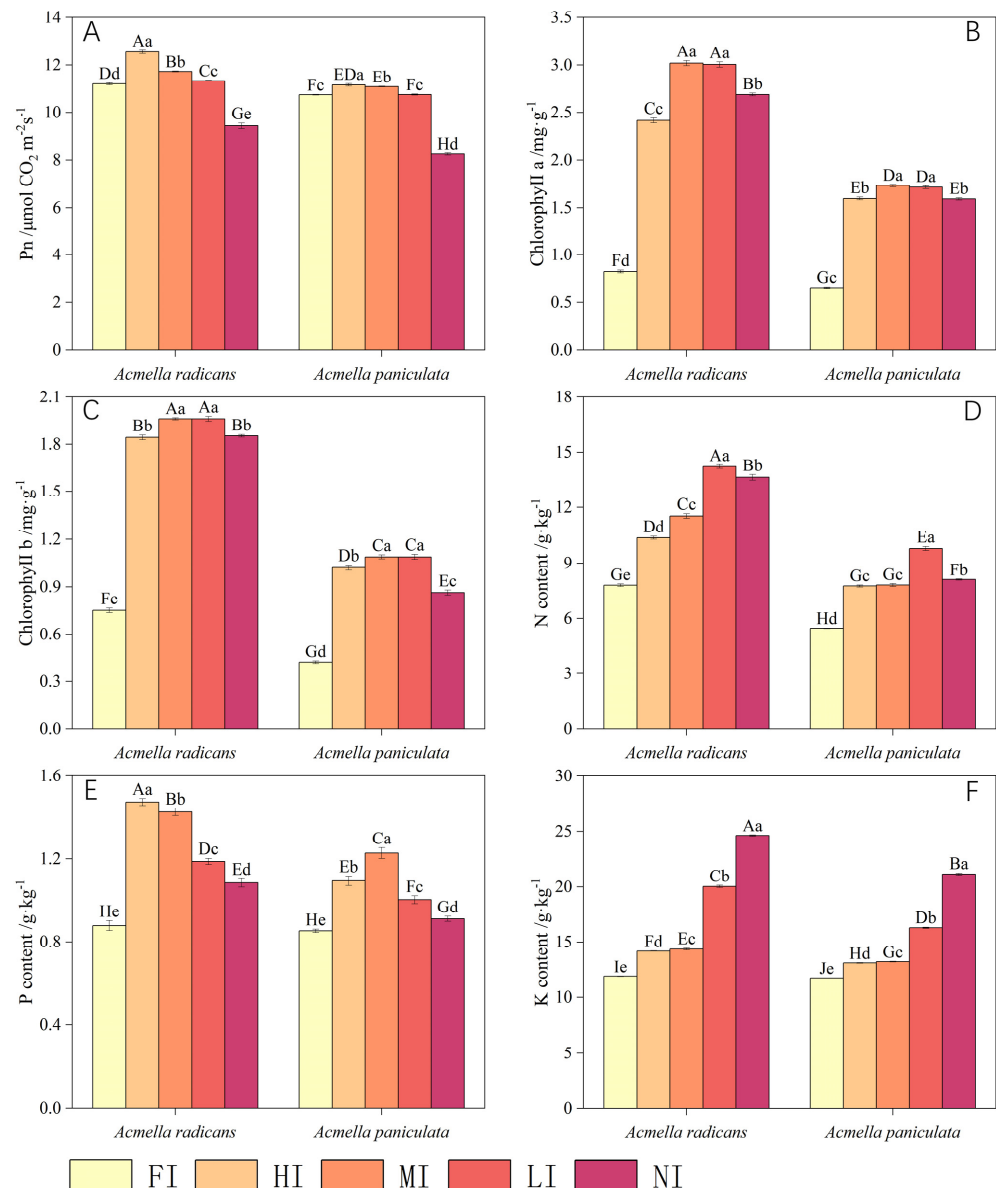


Figure 3. Photosynthetic and plant nutrient properties of *Acmella radicans* and *Acmella paniculata* under different light levels [FI = full irradiance (100%), HI = high irradiance (75%), MI = moderate irradiance (50%), LI = low irradiance (25%), NI = non irradiance (5%)] for (A) Pn, (B) chlorophyll a, (C) chlorophyll b, (D) N content, (E) P content, and (F) K content. Different small and capital letters above bars indicate a significant difference at 0.05 level for one species and between two species under different treatments, respectively.

3.4. Effect of Light on Plant Nutrients of *Acmella radicans* and *Acmella paniculata*

Plant N, P, and K content for both *A. radicans* and *A. paniculata* were significantly increased, with decreasing light intensity (Figure 3D–F), with less inhibition for *A. radicans* than for *A. paniculata* (Table 2). Plant N, P, and K content of *A. radicans* were higher than those of *A. paniculata* under the same light conditions (Figure 3D–F).

4. Discussion

Plant growth and reproduction for both *A. radicans* and *A. paniculata* responded significantly to a change in light intensity. However, *A. radicans* appeared to exhibit more efficient resource use, as is common with many invasive plants. *Acmella radicans* generally exhibited competitive advantages over *A. paniculata* in terms of having greater plant height, leaf area, biomass, seed number, Pn, chlorophyll content, and plant nutrient content, even at the lowest light level (5% solar irradiance). In addition, from high light intensities to low light intensities, most inhibition rates of plant parameters of *A. radicans* were less than those of *A. paniculata* under the same light intensities, indicating that the morphological and physiological characteristics of the invasive species were least affected by low light intensities.

Previous studies showed that *A. radicans* possessed a large leaf area, a high plant height, a large long-term soil seedbank, a broad seed germination niche, a strong allelopathic effect, and a high adaptability for light and soil water conditions [6,26–28,32]. However, there is a lack of comparative studies with its native congeners to determine if these characteristics help facilitate its invasion over native species.

Invasive alien plants are generally more tolerant to environmental stresses than native species. Higher morphological characteristics (e.g., plant height and biomass of plants) tend to increase competitive ability of invasive plants compared to sympatric species [33,34]. However, their population growth and spread may be limited by extreme environmental conditions such as low light levels [14,18,19]. Light is one of the most limiting environmental factors in terms of its ability to restrict population growth and spread of invasive plants [16,17].

Many invasive plants have greater plant height, greater basal stem diameter, and higher biomass than sympatric species to capture more light and soil nutrient resources in shaded environments [29,35,36]. For example, *Lantana camara* L. (Verbenaceae) exhibits acclimation to low light levels via increased plant height and leaf biomass [37]. *Phytolacca americana* L. (Phytolaccaceae) had the greatest plant height and total biomass, and the lowest reduction in biomass of each plant part under low light conditions when compared with those of its native congener, *P. acinosa* Roxb. [29]. This study found that plant height, basal stem diameter, and biomass of *A. radicans* were all greater than that of *A. paniculata*, enabling it to utilize limited light and soil nutrient resources more effectively under extreme conditions. In addition, from high light intensities to low light intensities, most inhibition rates of plant height, basal stem diameter, and biomass of *A. radicans* were less than those of *A. paniculata* under the same light conditions, indicating that the morphological characteristics of the invasive species were least less affected by low light.

In addition to greater morphological traits, many successful invasive plants are more likely to have a greater leaf area, higher photosynthetic rates, and lower tissue construction costs than native species, leading superior growth rates, biomass accumulation, and overall production [38–42]. As an example, the invasive tree fern *Sphaeropteris cooperi* (Hook. ex F.Muell.) R.M.Tryon (Cyatheaceae) had approximately five times larger total leaf surface area per plant, higher maximum rates of photosynthesis, and higher chlorophyll content compared to native tree ferns, *Cibotium chamissoi* Kaulf. (Cibotiaceae), *C. menziesii* Hook. & Arn. and *C. glaucum* (Sm.) Hook. & Arn. in the sun and shade [41]. A previous study

showed that *A. radicans* exhibited high growth even at 25% solar irradiance [32], and this study confirmed that both *A. radicans* and *A. paniculata* can survive, grow, and reproduce even at 5% solar irradiance. The bigger leaf area, higher Pn, and chlorophyll content of *A. radicans* compared to that of *A. paniculata*, demonstrated that the invasive species *A. radicans* has the potential to outcompete the native species *A. paniculata* through higher growth rates and more biomass accumulation. Moreover, from high light intensity to low light intensity, most inhibition rates of leaf area, Pn, and chlorophyll content of *A. radicans* were less than those of *A. paniculata* under the same light conditions, indicating that the physiological traits of the invasive species were least affected by low-light intensities.

These physiological traits tend to translate into higher reproductive ability than native species [43]. In fact, reproductive ability is positively correlated with the invasiveness of alien plants and high light levels could increase the seed production of invasive plants [40,43–45]. For example, high light level increased the production of racemes of both *P. americana* and its congener *P. acinosa*, but the invasive *P. americana* had more racemes than *P. acinosa* [42]. Similarly, the current study found that *A. radicans* generally had a greater reproductive ability than that of *A. paniculata*, and both species can also successfully reproduce even at 5% solar irradiance. However, *A. radicans* generally had a greater reproductive ability than that of *A. paniculata*. From high light intensity to low light intensity, inhibition rates of inflorescence number and seed number of *A. radicans* were less than those of *A. paniculata* under the same light conditions, showing that the reproductive traits of the invasive species were least affected by low light intensities. Additional data collections are needed to quantify these hypothetical differences in seed biology (e.g., seed length, size, and germination) between *A. radicans* and *A. paniculata* to explore its invasion mechanism under different environmental conditions.

Many invasive alien plants employ invasion mechanisms involving alterations of soil conditions with the resultant modifications in nutrient levels and availability which may actually lead to further invasion [33,34,46,47]. Invasive plant species tend to exhibit better functional traits and higher adaptability under high soil nutrient environments compared to surrounding native species [15,48–50]. Higher N, P, and K content in plants can be related to higher soil nutrient absorption which can promote increased growth rates, biomass accumulation, and overall production of exotic species [34]. Invasive plant species tend to have higher N and P concentrations in photosynthetic tissues by comparison to their native competitors [48], and rapidly growing invasive species may strategically promote nutrient cycling via resource acquisition [51]. A previous study indicated that intermediate irradiance levels tended to maximize nutrient absorption by *A. radicans* [32]. In this current study, plant N, P, and K content of *A. radicans* and *A. paniculata* increased significantly with increasing shade level, but *A. radicans* showed less inhibition than *A. paniculata*. This further demonstrated that *A. radicans* had higher soil nutrient or fertilizer nutrient absorption ability than *A. paniculata*. From high light intensity to shade, the inhibition of N, P, and K content of *A. radicans* was less than that of *A. paniculata* under the same light conditions.

5. Conclusions

Our results indicated that the invasive plant *A. radicans* had a greater phenotypic plasticity and higher ability to adapt different light conditions compared to the indigenous species *A. paniculata*. Except for total branch length and inflorescence number, plant height, leaf area, seed production, biomass, Pn, chlorophyll content, and plant nutrient content of *A. radicans* were clearly higher than those of *A. paniculata* under the same light conditions, showing that the invasive species has higher phenotypic plasticity than that of *A. paniculata*. The morphological and physiological traits of *A. radicans* and *A. paniculata* were initially increased with increasing shade before markedly declining at the lowest light

levels, with *A. radicans* generally less inhibited than *A. paniculata*, indicating that *A. radicans* is better adapted for shade than *A. paniculata*. Thus, the higher phenotypic plasticity and environmental adaptability of *A. radicans* adapted different light conditions by comparison to *A. paniculata* help make it more invasive. Although these general characteristics have been recognized in *A. radicans* in previous work, this is the first study to compare them with those of a non-invasive plant in the same genus. In order to improve the better understanding of *A. radicans* and explore more efficient control methods for *A. radicans*, additional comparing details on ecological impacts, biochemical traits, and molecular mechanisms of *A. radicans* and *A. paniculata* should be further examined.

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