Article Variation and Tradeoff of Leaf Traits of Karst Shrub in Southwest China

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Research

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Abstract

Long-term droughts were found to have guided the environmental selection of shrub plant characteristics in a karst region of China, as the plants were found to have developed a set of leaf trait combinations, including a small specific leaf area (SLA), leaf area (LA), and large leaf dry matter content (LDMC), that are known to be suitable for drought environments. Leaf traits of plants are not only the intuitive and operable taxonomic traits in plant taxonomy, but also reflect the responses and adaptations of plants to their habitats. This is helpful when trying to understand the role of environmental screening and when filtering plant functional traits. The objective of this investigation was to determine the leaf trait variations, adaptations, and patterns in the shrubs from a karst region in China. We investigated 11 leaf traits to quantify the variations in their trade-offs and the trait–habitat/species relationships for the shrubs at the Huanjiang karst ecosystem observation and research station, China, using multivariate analyses. There were significant intraspecific and interspecific changes in the leaf traits of the shrub plants, and there were differences among the traits. Except for carbon mass, nitrogen area, and phosphorous area, the interspecific variations of the leaf traits were generally higher than the interspecific variation. The correlation between the leaf traits in the karst shrubs was also significant. Species differences had a higher explanatory degree for the leaf traits than topography or soil nutrients. The findings of this study will enhance our understanding of the variations in leaf traits in the karst shrub regions and the adaptive strategies of the plants in degraded habitats. Furthermore, these results may provide scientific information to help guide vegetation recovery programs in the karst region of southwest China.

1. Introduction

Plant traits refer to a series of core plant properties that are closely related to plant colonization, survival, growth, and death. They can significantly affect ecosystem functions and reflect the responses of vegetation to environmental changes (Wright et al., 2004, 2007). Compared with most studies that are based on plant classifications and quantifications, plant traits have become a reliable focus when aiming to solve important ecological problems in populations at community and ecosystem scales (He et al., 2018). In recent years, research on the distribution patterns of plant traits has mainly focused on global and regional scales. At a global scale, many researchers have studied leaf morphology, structure, and physiological traits, nitrogen and phosphorus content in leaves, seed weight, tall tree, and trunk characteristics, and furthermore the famous global plant leaf economic spectrum and tree trunk economic spectrums have been developed (Wright et al., 2004, 2017; Reich et al., 2004, 2014). At a regional scale, investigations have reported the traits and functions of forest ecosystems along a 3700 km gradient in the south-north sample zone of eastern China, and developed a set of methods to scientifically deduce the traits of organ level measurements at the community scale (Tan et al., 2017).

Trade-offs are a common balance among plants traits, and is a combination of traits formed after natural selection. In other words, species are arranged in adaptive or competitive positions along a certain ecological strategy axis (Wright et al., 2004). These trade-offs not only include those between the
aboveground and underground traits of plants (Yao et al., 2010; Yang et al., 2019), but also the trade-offs between traits, such as the leaf and branch and trunk traits, leaf traits, reproductive traits and quantity, and reproductive traits and seedling leaves (He et al., 2018; Messier et al., 2017). The trade-offs between plant traits not only help to understand the differences of plant ecological strategies in different environments, but also explore the internal mechanisms of niche differentiation and species coexistence (Chave et al., 2009).

Plant traits determine the growth, reproduction, and survival of plants and play an important role in the distribution patterns of species along environmental gradients. The relationships between plant traits and the environment, are not only conducive to the study of ecosystem functions and the coexistence mechanisms of community species, but also for predicting the effects of global climate change on plant distributions (Wang et al., 2012). Many studies have shown that the life strategies of plants formed by different morphological and physiological traits among species, are reflected in their rapid resource acquisitions and high resource conservation, in different ecosystems and biological communities (Terashima et al., 2011). The distribution of plant traits at different scales, is the result of multi-factor filtrations from a large to small scale. Many studies have confirmed that climate factors, such as temperature, light, and precipitation, play a decisive role in the distribution of plant traits on a global or regional scale (Zhang et al., 2015, 2019). At a medium scale, land use and disturbance play a major role in plant traits (Ocheltree et al., 2012). However, at a small or local scale, the distribution of plant traits is determined by geomorphic and soil factors (Li et al., 2014). Compared with climatic and geographical factors, studies on the tradeoffs between habitats and plant traits, have been more concerned with degraded than non-degraded ecosystems.

The Karst region in the southwest of China is approximately 540,000 km$^2$, its primary forest is an evergreen broad-leaved forest and there is a seasonal rain forest. However, due to human disturbances, most of the evergreen and deciduous broad-leaved mixed forest and seasonal rainforest in the region of the limestone and dolomite have been degraded into secondary forests and shrubs (Nie et al., 2012). In recent years, with the implementation of major ecological projects such as the Grain for Green Program (GGP) by the government of the People's Republic of China, there has been a reduction in stony desertification and an increase in the restoration of vegetation (Zou et al., 2019). However, the loss of soil nutrients and soil water in the karst region is an ongoing problem because of crop cultivation by local famers (Du et al., 2015). At the same time, the rate of shrub changing successions to forest is becoming low, due to the serious seasonal droughts and the supply constraints of the soil nutrients (Tan et al., 2017). In addition, in the shrub communities in some regions, there is a serious leakage of soil nutrients and water, that is degrading them to grass communities or even bare rock desertification. This makes it difficult to realize the goal of sustainable vegetation recover in karst areas (Du et al., 2015; Zhang et al., 2017). Therefore, a better understanding of the shrub traits in the karst microhabitat is fundamentally important for rapid vegetation restoration of the degraded karst ecosystems in southwest China.

Although some previous studies have examined the relationship between vegetation and karst environmental factors (Du et al., 2015; Zou et al., 2020), there has been little research regarding the
variations and tradeoffs of the shrubs. In this research, we examined a suite of leaf traits in shrub plants based on field work in Huanjiang County, Guangxi Province. The aims of this research were to quantify the variations and trade-offs among the traits, and the leaf trait–karst habitat relationships, using multivariate analyses.

2. Materials And Methods

2.1. Research site

The research site was located in Mulian village (24.43°N-24.45°N, 108.18°E-108.20°E, 220 m above sea level), Dacai town, Huanjiang county, west of Guangxi province, which is the location of the Huanjiang karst ecosystem observation and research station, Institute of Subtropical Agriculture, Chinese Academy of Sciences (Fig. 1). According to the records of the weather station in Huanjiang county, from 1961 to 2019, the annual average temperature was 19.3 °C, the average temperature in January was 10.1 °C, the average temperature in July was 28.0 °C, and the average annual precipitation was 1750 mm, and the average annual sunshine time was 4422 h. The mother rock is limestone, and the soil is dominated by dark or brown calcareous soil with developed carbonate rocks. Karst is mainly distributed in the southwest of the county. The soil layer is shallow and the slope is large, which means that soil erosion is a serious issue. Furthermore, there is a serious level of rock exposure, resulting in a severe tendency for rocky desertification. The representative vegetations of the study area were grasses, shrubs, and secondary forests.

2.2. Field survey

From July to September 2019, thirty 10 × 10 m sample plots were set up, according to the different terrains and shrubs, and the diameter at breast height (DBH), height, and crown width of all the woody plants with DBH ≥ 1 cm in the quadrat were investigated and the species, quantity, height, and growth status of the shrubs and herbs were recorded. At the same time, the global positioning system (GPS) (E640 + MobileMapper) was used to record the longitude, latitude, altitude, and other geographic information of the inner center of each sample square, to investigate and record the slope, slope direction, slope position, rock exposure rate, and soil thickness. Five soil samples per plot were also collected from the surface soil (0–20 cm) according to the plum-flower pattern, and the samples were fully mixed to form the sample to be measured for soil nutrients. In this research, the soil pH, soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), available nitrogen (AN), available phosphorus (AP), and available potassium (AK) were measured using the methods previously described by Bao (2000).

2.3. Measurements of the leaf traits

Twenty-three dominant shrubs species were selected from the research plots, with 10–15 plants of each species. In the outer four directions of each shrub crown, 4 complete branches without pests, diseases, or epiphytes, were collected under full light, and 5–6 leaves were collected from each branch, resulting in
20–24 leaves being collected from each shrub. A multi-purpose leaf area meter (Regent Instruments, Quebec, Canada) was used to scan each leaf and obtain its area, aspect ratio, and other indexes. The leaves were put into the oven, killed at 105 °C for 20 min, dried at 85 °C for 48 h, and then the dry mass was measured. The carbon, TN, TP, and TK were also measured in the laboratory. The leaf traits examined were as follows: leaf area (LA, m²), specific leaf area (SLA, m²/kg), leaf mass per unit area (LMA, kg/m²), leaf dry matter content (LDMC, mg/g), leaf carbon content (C mass, g/kg), leaf nitrogen content (N mass, g/kg), leaf phosphorus content (P mass, g/kg), and leaf potassium content (K mass, g/kg).

2.4. Statistical analysis

The mean and standard deviations for each trait were calculated, and the differences of each trait between the different species were compared using the independent sample t test. Coefficients of variation (CV) were used to calculate the degrees of variation for each trait. The Pearson correlation test was used to analyze the functional correlations both between and within species. Using principal component analysis (PCA), the covariance matrix among the traits was determined after traits had been log-transformed. The effects of the topography, soil nutrients, and species on the trait variations were examined by one-way analysis of variance. The general linear model (GLM) was used to detect the effects of single factors, double factors, and multi-factor interactions. All statistical analyses were calculated using SPSS 17 software.

3. Results

3.1. Variations in the leaf traits of shrub plants

The mean values of leaf traits for LA, SLA, LMA, LDMC, C mass, N mass, P mass, K mass, N area, P area, and K area were 0.0092 m², 26.13 m²/kg, 0.05 kg/m², 431.48 mg/g, 414.07 g/kg, 1.57 g/kg, 0.06 g/kg, 0.37 g/kg, 0.026 g/m², 0.0026 g/m², and 0.018 g/m², respectively (Table 1). These traits also showed high variation, ranging from 0.00072 to 0.081 m² for LA, 10.35 to 79.18 m²/kg for SLA, 0.013 to 0.097 kg/m² for LMA, 190.95 to 937.65 mg/g for LDMC, 242.14 to 529.26 g/kg for C mass, 0.046 to 78.07 g/kg for N mass, 0.021 to 0.18 g/kg for P mass, 0.091 to 1.08 g/kg for K mass, 0.0019 to 1.13 g/m² for N area, 0.0012 to 0.0059 g/m² for P area, and 0.0039 to 0.055 g/m² for K area (Table 1).
Table 1
Summary statistics of leaf traits in karst shrub of southwest China

| Leaf traits | Mean | Minimum | Maximum | Standard deviation | Variable Coefficient (%) |
|-------------|------|---------|---------|--------------------|--------------------------|
| LA          | 0.0092 | 0.0007 | 0.081   | 0.013              | 141.30                   |
| SLA         | 26.13  | 10.35   | 79.18   | 16.02              | 61.31                    |
| LMA         | 0.050  | 0.013   | 0.097   | 0.023              | 46.00                    |
| LDM C       | 431.48 | 190.95  | 937.65  | 140.14             | 32.56                    |
| C mass      | 414.07 | 242.14  | 529.26  | 54.96              | 13.17                    |
| N mass      | 1.57   | 0.046   | 78.07   | 1.07               | 68.15                    |
| P mass      | 0.060  | 0.021   | 0.18    | 0.029              | 48.33                    |
| K mass      | 0.37   | 0.091   | 1.08    | 0.20               | 54.05                    |
| N area      | 0.026  | 0.0019  | 1.13    | 0.015              | 57.69                    |
| P area      | 0.0026 | 0.0012  | 0.0059  | 0.0011             | 42.31                    |
| K area      | 0.018  | 0.0039  | 0.055   | 0.013              | 72.22                    |

1 LA, leaf area (m2); SLA, Specific leaf area (m2/kg); LMA, Leaf mass per unit area (kg/m2); LDMC, Leaf dry matter content (mg/g); C mass, Leaf carbon content (g/kg); N mass, Leaf nitrogen content (g/kg); P mass, Leaf phosphorus content (g/kg); K mass, Leaf potassium content (g/kg); N area, Leaf nitrogen content per unit area (g/m2); P area, Leaf phosphorus content per unit area (g/m2); K area, Leaf potassium content per unit area (g/m2).

There were significant intraspecific and interspecific changes in the leaf traits of the shrub plants in the karst areas, and there were differences among the different traits (Fig. 2). From the average value of the species, the intraspecific variation of the N area and K area was large, while that of the C mass was the smallest. LA had the largest interspecific variation, while the P area had the smallest interspecific variation. Except for the C mass, N area, and P area, interspecific variations of the leaf traits were generally higher than interspecific variations.

3.2. Trade-offs in the leaf traits of shrub plants
There were significant positive or negative correlations among the leaf traits (Fig. 3; Table 2). LA was significantly correlated with SLA, P mass, and K mass. Except for C mass and K mass, the SLA was significantly correlated with the other traits. Significant correlations were also detected between LMA and LDMC, P mass, P area, and K area. The LDMC was only significantly correlated with the P area. There were significant autocorrelations between the N mass, P mass, K mass, and N area (Table 2). The PCA of the traits showed six independent axes of leaf trait variation (Table 3). The first three principal components collectively accounted for 70.00% of the total variation, whereas the other three principal components accounted for a further 24.32%. The first axes, which was predominantly related to SLA and P mass, together accounted for 36.64% of the total variation, whereas axes 2 and 3 together accounted for 33.36% of the total trait variation, indicating that LDMC, K mass, and K area dominated these axes. Axis 4, which accounted for 9.37% of all trait variation, was dominated by LA, C mass, N mass, and N area, whereas axes 5 and 6 were dominated by C mass and LA, respectively.
Table 2
Correlations and correlation probability between the leaf traits in the karst shrubs of southwest China

|     | LA | SLA | LMA | LDM  | C   | N   | P   | K   | N   | P   | K   |
|-----|----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|
| LA  | 0.00| 0.06| 0.34| 0.58 | 0.04| 0.00| 0.00| 0.00| 0.04| 0.96| 0.85|
| SLA | 0.44|     |     |      |     |     |     |     |     |     |     |
| LMA | -0.25| -0.86|     |      |     |     |     |     |     |     |     |
| LDM | -0.13| -0.45| 0.50| 0.99 | 0.52| 0.12| 0.11| 0.54| 0.00| 0.37|     |
| C   | -0.07| -0.04| -0.00| 0.00 | 0.73| 0.87| 0.57| 0.73| 0.96| 0.82|     |
| N   | 0.28| 0.38| -0.22| -0.09| -0.04| <.00| <.00| <.00| 0.97| 0.82|     |
| P   | 0.47| 0.73| -0.65| -0.21| -0.02| 0.56| 0.00| <.00| 0.16| 0.03|     |
| K   | 0.36| 0.30| -0.13| -0.22| -0.07| 0.45| 0.46| 0.00| 0.72| 0.05|     |
| N   | 0.28| 0.36| -0.21| -0.08| -0.04| 0.99| 0.55| 0.45| 0.96| 0.85|     |
| P   | -0.00| -0.44| 0.46| 0.46| 0.00| 0.00| 0.19| 0.04| 0.00| 0.05|     |
| K   | -0.02| -0.46| 0.60| 0.12| -0.03| -0.28| 0.62| -0.02| 0.26|     |     |

Note
See Table 1 for the meaning of the abbreviated terms.
Table 3
Trait loadings, eigenvalues, and the percentage of trait variation explained by the Principal Component Analysis (PCA)

| Traits | PC1  | PC2  | PC3  | PC4  | PC5  | PC6  |
|--------|------|------|------|------|------|------|
| LA     | 0.27 | 0.13 | -0.051 | 0.48 | 0.15 | 0.74 |
| SLA    | 0.44 | -0.20 | -0.040 | 0.12 | 0.043 | 0.010 |
| LMA    | -0.39 | 0.34 | 0.00057 | -0.085 | -0.070 | 0.21 |
| LDMC   | -0.24 | 0.23 | 0.49 | 0.12 | -0.054 | 0.28 |
| C mass | -0.031 | -0.06 | 0.11 | -0.43 | 0.88 | 0.14 |
| N mass | 0.34 | 0.333 | 0.19 | -0.41 | -0.19 | 0.086 |
| P mass | 0.42 | 0.11 | 0.23 | 0.27 | 0.18 | -0.32 |
| K mass | 0.24 | 0.42 | -0.44 | 0.079 | 0.14 | -0.16 |
| N area | 0.34 | 0.33 | 0.20 | -0.41 | -0.19 | 0.083 |
| P area | -0.15 | 0.38 | 0.41 | 0.37 | 0.21 | -0.39 |
| K area | -0.17 | 0.47 | -0.49 | 0.0033 | 0.10 | -0.042 |
| Eigenvalue | 4.03 | 2.33 | 1.33 | 1.03 | 0.99 | 0.65 |
| Explained (%) | 36.64 | 21.25 | 12.11 | 9.37 | 8.97 | 5.98 |
| Cumulative (%) | 36.64 | 57.89 | 70.00 | 79.37 | 88.34 | 94.32 |

Note
See Table 1 for the meaning of the abbreviated terms.

3.3. Multi-factorial control of leaf trait variation

Factor analysis of the variance showed that species differences had a high explanatory degree for leaf traits (Table 4). The $R^2$ value between species and leaf traits ranged from 0.32 to 0.86. Among these traits, the species highly explained the variation of LA, P mass, K mass, and K area. The effects of topography on the variations of the leaf traits was small, but the effects on the K area were relatively large (Table 4). Similarly, the different soil nutrients had small effects on the variation of leaf traits. The interactions between the topography and soil nutrients only had a small effect on most trait variation than that of topography and soil nutrients separately (Table 4).
Table 4
Effects of species, topography, and soil nutrient on leaf trait variations ($R^2$ value) in karst shrub of southwest China

| Variables | LA  | SLA | LMA | LDM C | C mass | N mass | P mass | K mass | N area | P area | K area |
|-----------|-----|-----|-----|-------|--------|--------|--------|--------|--------|--------|--------|
| Species   | 0.86| 0.69| 0.75| 0.57  | 0.33   | 0.32   | 0.85   | 0.82   | 0.32   | 0.49   | 0.82   |
| Topography| 0.19| 0.11| 0.21| 0.18  | 0.11   | 0.09   | 0.26   | 0.17   | 0.09   | 0.21   | 0.33   |
| Soil nutrient| 0.39| 0.07| 0.13| 0.18  | 0.10   | 0.14   | 0.29   | 0.40   | 0.14   | 0.16   | 0.29   |
| Topography × Soil nutrient| 0.11| 0.04| 0.01| 0.05  | 0.03   | 0.06   | 0.05   | 0.12   | 0.05   | 0.01   | 0.13   |

Note
See Table 1 for the meaning of the abbreviated terms.

4. Discussion
4.1. Variations in the leaf traits and its control factors

In this study, it was found that 11 leaf traits from the 10 shrub plants in the karst area had different degrees of variation within and between the species (Fig. 2). Previous studies have shown that interspecific variations play a dominant role in the variation of plant functional traits, but increasing evidence has shown that intraspecific variation is not negligible (Albert et al., 2010; Jiang et al., 2016).

The average intraspecific variation of the leaf traits in this research was 23%, which was like that of previous investigations (Zhong et al., 2018). The range of intra-specialty variation of the karst plant traits was also lower than that of the non-karst plants, which may reflect the small levels of morphological plasticity in the harsh habitat conditions (Auger et al., 2013).

The interspecific variations of the plant traits differed with the different environmental conditions (Zhong et al., 2018). Our data showed that the range of interspecific variations for the 11 traits ranged from 2.9–121.3%, and the variations for the LA were significantly higher than those for the other traits. Plant traits
are jointly determined by genetic factors and environmental conditions (Yao et al., 2010). Among species with different genetic backgrounds or different taxon, the leaf traits between the species vary more than those of a branch, which indicated that the performance of the leaf was relatively unstable among species.

On the other hand, variations of the leaf and root traits also varied with the habitat conditions, to adapt to their living environment (Yang et al., 2019). In this research, we also found that the leaf traits were affected by the topography and soil nutrients. However, the extent to which environmental factors had an effect was less than that of species groups (genetic background) (Table 4). Consequently, the phylogenetic development of plants, i.e., their evolution and taxonomic background, has a great influence on sexual differentiation, sometimes even exceeding the influence of environmental factors (Chen et al., 2014; Ni et al., 2015). However, species groups have a low degree of explanation for some leaf trait variations, which may be closely related to the high heterogeneity of the karst habitats (Zhong et al., 2018).

4.2. Co-variation of different leaf traits

In the process of plant growth and long-term adaptation to the environment, the traits showed a certain correlation with the comprehensive action of physiological, phylogenetic, and environmental factors, and finally formed a series of optimal combinations of functional traits adapted to specific environments (Kerkhoff et al., 2006). In this study, it was found that the correlations between leaf traits in the karst shrubs was significant. For examples, we detected significant correlations between the SLA and LA at the species level (Table 2), which was consistent with the findings of previous but recent investigations (Yang et al., 2019; Cornelissen et al., 2003).

LMA and LDMC can both represent the utilization of environmental resources by plants to a certain extent, and are closely related to a plants adaptation strategies to the environment, and can reflect the adaptation characteristics of plants to different habitats (Cornelissen et al., 2003). The positive correlation between the two has been universally confirmed (Wilson et al., 1999). The results of this study were also in agreement with previous research (Table 2). In general, species distributed along the LMA-LDMC axis (the regression line between LMA and LDMC) have different utilization methods of the environmental resources, especially those distributed at both ends of the resource utilization axis. Plants with high LMA and LDMC usually live in poor environmental conditions (for example, drier or colder), and have strong resistances to oppression (Feng et al., 2010). They maintain their growth and development by accumulating captured resources. Plants with low LMA and LDMC, on the contrary, generally live in a superior environment and have high production capacity, but poor resistance to harsh environments (Feng et al., 2010).

In addition, the nutrient content of the leaves is related to the utilization of plant resources or the strategies of plant adaptation to the environment. Generally, the photosynthetic capacity and respiratory consumption of plants with high nutrient content in leaves, especially those with high N content, are usually strong, and they adapt to the environment through rapid nutrient cycling. Those with low nutrient
content in their leaves, with low photosynthetic capacities, will survive through rapid nutrient cycling (Wright et al., 2004, 2007; Feng et al., 2010). Here, we found that there was no significant correlation between LMA, LDMC, and the nutrient contents in a single area (except for P mass). With the increase of plant LMA and LDMC, the nutrient content per unit area constant, which is not consisted with some previous research (Jiang et al., 2016; Zhong et al., 2018). Previous studies indicated that when the N and P areas are constant, the N and P masses will decrease with increasing leaf thickness (LMA and LDMC), but this decrease will be offset by the increases of N and P areas. from the increase of the LMA and LDMC. Therefore, N mass and P mass have no significant relationship with LMA and LDMC (Feng et al., 2010). Here, our data showed that N mass was not significantly related with LMA and LDMC, while the P mass not (Table 2).

### 4.3. Adaptation strategies of shrub plants in karst areas

In this investigation, although there were shrub plants with similar habitats and resources, 11 leaf traits showed significant differences in the different species. This not only reflects the different adaptation strategies of the different species to the local environment, but also reflects the divergence of the functional strategies caused by competitive exclusion among co-existing species (Yao et al., 2010; Zhang et al., 2010). The plants traits in different environmental conditions and with similar functional groups, also have different characteristics. The dominant shrub of shrub vegetation in karst areas of Guizhou had lower LA and LDMC, but the SLA was significantly higher than that of this study (Jiang et al., 2016). Although both of Guangxi and Guizhou belong to the karst area, their vegetation types and landforms are different.

Compared with the non-karst areas of the same latitude, the SLA, LA, and LDMC of the plants in the karst areas and non-karst areas showed significant differences. The SLA and LA of the plants in the karst area were smaller than those in the non-karst area, while the LDMC and TDMC were larger than those in the non-karst area (Yao et al., 2010; Xu et al., 2016). Plants in the non-karst areas had a large SLA and LA, showing a strong ability to capture light energy resources, and that they could adapt to the resource-rich environment. Seasonal water deficits in the karst soil seriously affected the growth and development of the plants in the karst areas (Jiang et al., 2016). Therefore, after long-term droughts guiding environmental selection, plants in the karst areas have formed a set of leaf trait combinations with small SLA, LA, and large LDMC, which are suitable for drought environments. Smaller SLA and LA are beneficial for plants to reduce transpiration and retain water, thus maintaining a lower growth rate, while larger LDMC are beneficial as they help plants to store nutrients (Jiang et al., 2016; Wilson et al., 1999).

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**Figures**

![Map of China](image)

**Figure 1**

The field site in this research. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 1

The field site in this research. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Coefficient of interspecific/intraspecific variations of the leaf traits in the karst shrubs. Note: See Table 1 for the meaning of the abbreviated terms.
Figure 3

Color map of the correlations (r, left) and correlation probability (p, right) between leaf traits. Note: See Table 1 for the meaning of the abbreviated terms.
Figure 4

Trait dimensions from the first four principal component (PC) analysis. Note: See Table 1 for the meaning of the abbreviated terms.
Figure 4

Trait dimensions from the first four principal component (PC) analysis. Note: See Table 1 for the meaning of the abbreviated terms.