Adaptation strategies of leaf traits and leaf economic spectrum in urban garden plants

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Abstract

In order to explore the adaptation strategies of urban garden plants leaf traits and the relationship of different life forms to climate zone. In this study, we used Mudanjiang of Heilongjiang Province and Bozhou of Anhui Province as the research sites, 17 and 9 woody garden plants were selected respectively, measured 7 leaf morphological characters and 4 photosynthetic pigment contents. One way ANOVA was used to reveal the variation characteristics of leaf functional traits of trees, shrubs and vines in two urbans. Two-way ANOVA was used to reveal the plant leaf traits under climate and life form. Pearson correlation analysis and principal component analysis was used to calculate the correlation coefficient between leaf functional traits of plants in the two places. Leaf dry matter content (LDMC) and Vein density (VD) of different life forms in Mudanjiang were higher than Bozhou ($P < 0.05$), the Relative water content (RWC) in Bozhou was higher, while Vein density (VD) of trees and shrubs in two urbans were significant (($P < 0.05$), but the vine was not significant. The tree and shrub species photosynthetic pigments were larger in Mudanjiang, but it was opposite in vines. Both leaf vein density (VD) and stomatal density (SD) showed a very significant positive correlation in two nrbans ($P < 0.01$), and both were significantly positively correlated with specific leaf area (SLA) ($P < 0.05$), negatively correlated with leaf thickness (LT), and the relationship between pigment content were closer. The response was obvious differences in leaf traits of different life forms species in urban to climate, but the correlations between the traits showed convergence, which reflects that the adaptation strategies of garden plant leaves to different habitats are both coordinated and relatively independent.

Introduction

Leaves are the bridges connecting plants and the environment, and also the bridges connecting plants and ecosystems (Long et al. 2011; Roche et al. 2004). Leaf structural traits (eg. specific leaf area, leaf thickness, stomatal density, leaf vein density and leaf dry matter content) and physiological traits (eg. photosynthetic rate and pigment) can reflect the adaptive strategies of plants to climate (Brodribb et al. 2010; Carlson et al. 2015; Wang et al. 2016; Khan et al. 2020). The leaf traits which are key attributes of plant growth status reflect the adaptation and response of plant to the growth environment (Siebert et al. 2015; Pan et al, 2018). The differences of leaf traits are affected by many factors (eg. interspecific, community, longitude and latitude, etc.) (Siebert et al. 2015; Read et al. 2017; Zirbel et al. 2017; Wang et al. 2021). All of these are based on studies of plants growing naturally in the wild. With the intensification of urbanization, the research on the functional properties of urban landscape plant leaves has gradually been carried out (Han et al. 2018; Zhao et al. 2019; Li et al. 2022). But most of the researches are conducted among different species under the same climate. The research on the leaf properties of urban garden plants with different life forms under different climates is still in the exploring.

Plant leaf traits are the focus of ecological research in recent years. There have been many studies on the relationships of plant leaf traits (Garnier et al. 2001; Freshet et al. 2010). The relationships generally exist in plant populations, communities and biota (Wright et al. 2004; Liu et al. 2010), which is known as the Leaf Economic Spectrum (LES). The LES indicates that there are close relationships of leaf traits (Tjoelker et al. 2005). Leaf traits can reflect the distribution of plants and their adaptive characteristics to different habitats so that they are the preferred indicator in the study of plant comparative ecology (Garnier et al. 2001; Reich et al. 1998; Wilson et al. 1999). The leaf traits reflect the survival adaptation strategies adopted by plants to maximize carbon income (Cornelissen et al. 2003; He et al. 2018). In analyzing the comprehensive impacts of environmental factors, the principal component analysis (PCA) was proved as an effective approach (Kramer-Walter et al. 2016; de la Riva et al. 2018; Wang et al. 2018). There are certain synergies and balances between plant leaf functional traits. That means leaf tissue construction requires balances in plant growth and resource acquisition (Carlson et al. 2015; de la Riva et al. 2016). It has been pointed out that the leaf function traits within the species are greatly affected by climate factors, and the balances of traits are widespread (Bucher et al. 2016). Previous studies on the relationship of traits have focused on the natural growth conditions of wild plants. While urban garden plants have some differences in plant traits due to environmental interference. It is unknown whether the leaf trait relationships which are under different climates of different species is different in urban.

In this study, we sampled leaves at two climatic zones with different precipitation, temperature and altitude (Table S1) as the research object (Table 1), which are common woody plants in the campus (17 species in Mudanjiang, Heilongjiang Province) and (9 species in Bozhou, Anhui Province). For each species, we measured 11 functional traits of plant leaves, covering morphological and physiological characteristics (Table 2). Our goal was to explore the variation of leaf traits of garden plants with different life forms in the two cities and the correlation of leaf traits at the species level, so as to reveal the adaptive strategies adopted by plants in the two cities to adapt to different climates. We tested two hypotheses: 1) There are differences in the response of leaf traits to climates among species and different life forms; 2) The LES is widespread (Reich 2014), which is not affected by climate change. Studying the changes and correlations of these attributes in species and life forms can help us understand the ecological adaptation strategies of urban plants with different life forms under different climates. It provide some scientific basis for the selection and application of urban garden plants.

Table 1
List of species studied, family and life form.

Site	Species	Family	Genus	Life form
Mudangjiang	*Ulmus pumila* L cv 'Jinye'	Ulmaceae	Ulmus	Tree
	Acer saccharum Marsh.	Aceraceae	Acer	Tree
	*Acer pictum*Thunb. ex Murray	Aceraceae	Acer	Tree
	Acer mandshuricum Maxim.	Aceraceae	Acer	Tree
	Betula platyphylla Suk.	Betulaceae	Betula	Tree
	Prunus cerasifera f. *atropurpurea*	Rosaceae	Prunus	Tree
	Padus virginiana 'Canada Red'	Rosaceae	Padus	Tree
	Sorbus pohuashanensis	Rosaceae	Sorbus	Tree
	Spiraea thunbergii Bl.	Rosaceae	Spiraea	Shrub
	Spiraea x bumalda cv.Gold Flame	Rosaceae	Spiraea	Shrub
	Berberis thunbergii DC.	Berberidaceae	Berberis	Shrub
	Acer ginnala Maxim.	Aceraceae	Acer	Shrub
	Physocarpus opulifolius var.*luteus*	Rosaceae	Physocarpus	Shrub
	Physocarpus opulifolius 'Summer Wine'	Rosaceae	Physocarpus	Shrub
	Parthenocissus quinquefolia (L.) Planch.	Vitaceae	Parthenocissus	Vine
	Parthenocissus tricuspidata	Vitaceae	Parthenocissus	Vine
	Vitis vinifera L	Vitaceae	Vitis	Vine
Bozhou	*Acer pictum*Thunb. ex Murray	Aceraceae	Acer	Tree
	Prunus cerasifera f. *atropurpurea*	Rosaceae	Prunus	Tree
	Ginkgo biloba L.	Ginkgoaceae	Ginkgo	Tree
	Acer palmatum Thunb.	Aceraceae	Acer	Tree
	Loropetalum chinense var. *rubrum*	Hamamelidaceae	Loropetalum	Shrub
	Nandina domestica Thunb.	Berberidaceae	Nandina	Shrub
	Photinia × fraseri Dress	Rosaceae	Photinia	Shrub
	Parthenocissus tricuspidata	Vitaceae	Parthenocissus	Vine
	Vitis vinifera L.	Vitaceae	Vitis	Vine

Table 2
Leaf trait parameters and variation characteristics of plants in two urbans in China. Abbreviations: LT: Leaf thickness; LA: Leaf area; LDMC: Leaf dry matter content; RWC: Leaf relative water content; SLA: Specific leaf area; SD: Stomatal density; VD: Leaf vein density; Chla: Chlorophyll a; Chlb: Chlorophyll b; Car: Carotinoid; Chl: Chlorophyll.

Urban in China	Leaf trait	Mean ± SD	Min	Max	Kurtosis	Skewness	CV(%)
Mudangjiang	LT	0.17 ± 0.03	0.11	0.24	-0.21	0.23	19.33
	LA	25.48 ± 25.91	3.06	119.74	12.39	3.31	101.70
	LDMC	0.61 ± 0.12	0.34	0.85	1.05	-0.19	19.33
	RWC	0.49 ± 0.14	0.26	0.81	0.71	0.40	27.40
	SLA	235.25 ± 72.83	127.55	406.54	0.61	0.66	30.96
	SD	218.32 ± 122.11	75.90	584.79	4.29	1.77	55.93
	VD	5.91 ± 1.48	3.38	9.17	0.31	0.29	25.11
	Chla	4.37 ± 5.11	0.22	17.58	1.45	1.43	116.96
	Chlb	1.19 ± 1.40	0.01	4.68	1.36	1.48	118.06
	Car	2.43 ± 1.17	0.52	5.32	1.02	0.71	47.96
	Chl	5.56 ± 6.49	0.26	22.27	1.45	1.45	116.85
Bozhou	LT	0.17 ± 0.03	0.13	0.21	-1.53	-0.16	15.92
	LA	29.23 ± 37.39	3.15	124.12	6.67	2.49	127.95
	LDMC	0.38 ± 0.83	0.23	0.48	-0.94	-0.53	22.29
	RWC	0.75 ± 0.08	0.63	0.85	-0.84	-0.34	10.40
	SLA	145.58 ± 47.81	77.10	203.17	-1.79	-0.13	32.84
	SD	354.36 ± 109.41	210.61	559.29	0.13	0.58	30.87
	VD	3.56 ± 1.23	1.44	5.10	-0.34	-0.60	34.70
	Chla	4.43 ± 2.81	1.22	9.04	-1.28	0.43	63.46
	Chlb	1.00 ± 0.86	0.17	2.17	-2.20	0.39	86.41
	Car	1.10 ± 0.65	0.55	2.57	2.92	1.62	59.35
	Chl	5.42 ± 3.54	1.57	10.53	-1.94	0.30	65.26

Methods

Two study sites were chosen from the south-north environmental gradient in China. Mudanjiang is located in the southeast of Heilongjiang Province, China. Its terrain is mainly mountainous and hilly. The altitude ranges from 300 to 800 m and the average is 230 m. Soil is mainly dark brown. Spring is short, quick to warm up, windy and easy to drought; summer is warm and rainy; autumn is short and quick to cool down; winter is long and cold. Rainfall is mainly concentrated in summer and it has the characteristics of simultaneous rain and heat (Lu et al. 2018). Bozhou is influenced by the meandering and cutting changes of rivers and the successive southern flooding of the Yellow River. It is formed a plain in which posts, slopes and saucer-shaped depressions are distributed among each other, with the geomorphological characteristics of "big flat and small uneven". The soil is mainly sandy concretionary black soil, followed by tide soil, brown soil with little lime soil. Bozhou has a mild climate, sufficient sunlight, moderate rainfall, a long frost free period, with an average is 216 d. The four seasons are distinct in Bozhou there the spring temperature is changeable, the summer rain is concentrated, the autumn is crisp, and the winter is long and dry (He et al. 2016). The location and climate characteristics of the two cities are shown in Table S1 and Fig. 1.

We selected common local garden plants in two cities in late September 2020 (Table 1) in our study. Seventeen species of woody plants (8 species of trees, 6 species of shrubs, and 3 species of vines) were selected from the campus of Mudanjiang Normal College, and nine species of woody plants (4 species of trees, 3 species of shrubs, and 2 species of vines) were selected from the campus of Lixin County No. 1 Middle School. At each site, six standard plants of each species randomly were selected for leaf sampling, and the tree height and diameter at breast height (DBH) were recorded. 60 sunny leaves were selected for each plant. The leaf samples were divided into two subsamples: one was gently washed with deionized water and immediately fixed in formalin-aceto-alcohol (FAA) solution (90 ml of 50% ethanol, 5 ml of 100% glacial acetic acid and 5 ml of 37% formaldehyde) for Leaf vein analysis; while the other was put into Ziploc bags for morphological and physiological analyses. The selected leaves were packed and stored in a portable refrigerator and then were brought back to the laboratory.

In the laboratory, the leaf samples in each Ziploc bag were cleaned with distilled water and absorbed the water with filter paper. We weighed five groups leaves (6 leaves/group) in the balancend recorded the fresh leaf weight as W1. Then putted it into distilled water for more than 6 hours and made the leaf absorbed water to reach saturation. Every leaf was took out and dried to no water residue on the surface and then was weighed and recorded the saturation fresh weight as W2. Then dried to constant weight at 65°C to get the leaf dry mass (accuracy = 0.0001g), and recorded the dry weight as W3. Leaf dry matter content (LDMC) was calculated as: LDMC = W3/W1. Relative water content (RWC) was calculated as: RWC=(W1-W3)/(W2-W3).Leaf thickness was measured as far as possible to avoid the main veins of the leaves and the secondary veins on both sides with vernier caliper(0.02mm).We measured 3 times for 1 group/plant(6 leaves)and with repetition of 5 groups/plants, and then calculated the average thickness of each leaf (Leaf thickness, LT). The leaves of 5 plants/groups used for leaf morphological analysis were all scanned with a scanner (dpi = 400, Epson Telford Ltd, Telford, UK), then dried to constant weight at 65°C to get the leaf dry mass. The scanned images of leaves were processed using Image-J 136b (National Institutes of Health, MD, USA) to obtain leaf area. Specific leaf area (SLA) was calculated as: leaf area divided by leaf dry mass. The stomatal density was measured by nail polish impression method as discribed in Franks et al. (2009). Transparent nail polish was uniformly applied to the leaf abaxial surface, allowing it to harden, then using clear cellophane tape to transfer the impression of stomata to a microscope slide. The properties of the stomata were observed by a compound microscope (BX-51, Olympus Corporation, Tokyo, Japan). There were three images selected from each leaf, and total 45 number observation fields for 15 leaves for one species to count and measured. The stomatal density (SD) was calculated as: stomatal number divided by observation field area.

Referring to the mixed solution extraction method of Cang et al (2013), 0.5g leaves were cut them into tubes which was added 80% acetone. The leaves were extracted in dark for 12h and measured the content of photosynthetic pigments at 662nm, 644nm and 440nm respectively with a visible spectrophotometer (INESA, model L3S).

The calculation of Chlorophyll content;

$Chla = 12.21OD_{663}-2.81OD_{646}$

$Chlb = 20.13OD_{646}-5.03OD_{663}$

$Car=(1000OD_{470}-3.27C_a-104C_b)/229$

Chlorophyll content (Chl) (mg g^{-1}) = N × Vt × C/W

C is the concentration of pigment (mg•L^{-1}); Vt is the volume of extract (ml); N is the dilution multiple, W is the fresh weight of the sample (g).

Descriptive statistical analysis was performed for each trait in two areas. The coefficient of variation (CV = standard deviation/mean × 100%) was used to characterize the degree of variation of each trait. Two-way ANOVAs was used to calculate the effects of climate and life forms on each trait, and one-way ANOVA was used to calculate the mean and standard error of each trait of leaves of trees, shrubs and vines at the two areas. Before the calculation, all the data were tested for normal distribution and chi-square. Differences between treatments were tested using Duncan (D) if the hypothesis was met, otherwise differences between treatments were tested using Dunnett, s T3 (LSD, α = 0.05). Pearson correlation analysis and principal component analysis were calculated to explore the interrelationships between and within the traits of the plants in the two areas. Pearson's correlation analysis was calculated using the 'corrplot' package in 'R'(Wei 2017). Microsoft Excel 2003 and SPSS software (version 19.0, SPSS, Inc., Cary, NC, USA) were used to process the data. Microsoft Excel 2003, Origin 2021 were used for plotting.

Results

Variation In Plants Leaf Traits In Two Areas

The descriptive statistics of 11 leaf traits of the plants in the two areas showed that the traits varied widely (Table 2). The variation degree in pigment content of 17 plants was larger than that of morphological traits in Mudanjiang. The largest variation was Chlb (118.06%) and the smallest were LMDC and LT (19.33%). In Bozhou, the largest variation of 9 plants was SLA (127.95%) and the smallest variation was RWC (10.40%). Leaf morphological traits were significant affected by climates except for LT, and pigment content were also non-significant effects. LA, LDMC, and RWC were significant affected by life forms and the interactions of climates and life forms ($P < 0.001$) (Table 3).

Table 3
Two-way analysis of variance (ANOVA) for the effects of climatic (Mudangjiang; Bozhou), life form (Tree; Shrub; Vine), and their significant interaction to plant morphological traits and physiological traits in China. Abbreviations: LT: Leaf thickness; LA: Leaf area; LDMC: Leaf dry matter content; RWC: Leaf relative water content; SLA: Specific leaf area; SD: Stomatal density; VD: Leaf vein density; Chla: Chlorophyll a; Chlb: Chlorophyll b; Car: Carotinoid; Chl: Chlorophyll.

Variables	***df***	***P values***										
		LT	**LA**	**LDMC**	**RWC**	**SLA**	**SD**	**VD**	**Chla**	**Chlb**	**Car**	**Chl**
Climatic (Cl)		1	0.550	**0.037**	**0.001**	**0.002**	**0.001**	**0.032**	**0.008**	0.921	0.802	0.062	0.983
Life form(Lf)	2	0.058	**0.004**	**0.029**	**0.019**	0.317	0.382	0.132	0.302	0.224	0.108	0.285
Cl×Lf	1	0.547	**0.023**	**0.047**	**0.022**	0.171	0.542	0.361	0.550	0.994	0.320	0.638
Note: p-values in bold indicate significant effects. Non-significant interaction effects are not displayed.												

Plants Leaf Traits Of Different Life Forms In Two Areas

The leaf morphological traits in two areas were different (Fig. 2). The SLA, LDMC, VD and LT of trees, shrubs and vine in Mudanjiang were significantly higher than that in Bozhou (Fig. 2a,c,f,g), while the LA, RWC and SD were the opposite. The SLA of trees, shrubs and vine in Mudanjiang were higher than Bozhou at 46.87% 147.35% and 27.78%, and RWC were lower than Bozhou at 36.96%, 41.39% and 14.46% (Fig. 2a, d). In terms of life forms, the SLA, LA and RWC of vines were highest, and in shrubs were lowest at both areas. LT was shrubs > vines > trees, and VD was trees > shrubs, but SD were inconsistent. The leaves pigment content of life forms were also differed between the two sites (Table 4). The pigment contents of trees and shrubs in Mudanjiang are higher than that of Bozhou, while pigment contents of vines showed the opposite. The pigment content of shrubs and vines differed significantly between the two areas except Car. The largest difference is Chlb of shrubs, which was 6.67 times higher in Mudanjiang than that in Bozhou. Car of trees in two areas differed significantly and that in Mudanjiang was twice as much as Bozhou. In terms of life forms, the pigment content of all plants in Mudanjiang showed shrubs > trees > vines, while the opposite was showed in Bozhou.

Table 4
Pigment contents of tree, shrub and vine in two urbans in China.

Life form	Site	Chlorophyll a (mg g^{-1})	Chlorophyll b (mg g^{-1})	Carotenoids (mg g^{-1})	Chlorophyll (mg g^{-1})
Tree	Mudangjiang	4.03 ± 1.72a	1.14 ± 0.50a	2.55 ± 0.30 a	5.17 ± 2.21a
	Bozhou	3.9 ± 1.49a	1.2 ± 0.50a	1.29 ± 0.48 b	5.1 ± 1.96a
Shrub	Mudangjiang	6.35 ± 2.57a	1.64 ± 0.70a	2.9 ± 0.58 a	7.99 ± 3.26a
	Bozhou	2.88 ± 0.62b	0.25 ± 0.05b	0.73 ± 0.09 b	3.12 ± 0.60b
Vine	Mudangjiang	1.31 ± 0.41b	0.41 ± 0.07b	1.18 ± 0.33 a	1.72 ± 0.48b
	Bozhou	7.8 ± 1.24a	1.71 ± 0.22a	1.25 ± 0.11 a	9.51 ± 1.02a
Note: Different lowercase letters indicate significant differences at P < 0.05 levels.					

Correlation Between Leaf Traits In Two Areas

There were correlations between the various of plant leaf morphological traits in two areas (Fig. 3). There was significantly negatively correlated between LT and SLA in two areas (R^2 = 0.527, P< 0.05, R^2 = 0.533, P< 0.001). Compared with Mudanjiang, there was a stronger positive correlation between VD and SD in Bozhou (R^2 = 0.372, P< 0.01, R^2 = 0.791, P= 0.01). SLA in two areas showed significant positive correlations with VD and SD, and the correlation between SLA and VD was higher in Bozhou (R^2 = 0.587, P< 0.05). There was significant negative correlations between LT and VD in two areas. There was a significant negative correlation between LT and SD in Bozhou (R^2 = 0.587, P< 0.05).We found that there were positive correlations between the various of pigments in two areas except for the correlation of Car and Chl in Bozhou. But the positive correlation between Chla and Chlb was stronger in Mudanjiang (R^2 = 0.966, P< 0.001).

Principal Component Analysis Of Leaf Traits In Two Areas

Principal component analysis showed that the first and second sequence axes of the two areas cumulatively explained 84.81% and 78.86% of the total variation in leaf traits, respectively (Fig. 4a, b).The first axis of Mudanjiang explained 67.80% of the variation in leaf traits and was negatively correlated with SLA, LA, SD, VD, LDMC, RWC, and RWC, and positively correlated with Chl, Chla, Chlb, Car, and LT. The second sequence axis explained 17.01% of the variation in leaf traits and was positively correlated with LA, RWC, LDMC, LT, Chlb, Chl, Chla, SLA, and negatively correlated with Car, VD, and SD. The first sequence axis (62.72%) and the second sequence axis (16.14%) of Bozhou explained the total variation of leaf traits. The first axis was negatively correlated with LDMC, LT, and RWC, positively correlated with LA, SLA, Chlb, Chla, Chl, Car, VD, and SD. The second axis was positively correlated with VD, SD, LDMC, SLA, and LA, and negatively correlated with Chl, LT, RWC, Chla, Car, and Chlb.

Discussion

The variation of plant traits were influenced by the environment and symbiotic organisms (Xu et al. 2019). Plants could produce similar traits in local habitats, while divergence traits of plant were produced by competition. There were ecological niche differentiation of species coexistence and reflected the mechanism of species coexistence. In this study, there were different degrees of variations in leaf traits in 17 and 9 garden plant species in the two areas. The average of variations which were 61.78% (Mudanjiang) and 49.95% (Bozhou) reflected the response of species to adapt to environmental changes during community construction (Plourde et al. 2015). That proved our first hypothesis. The higher variations of all the plant traits in two areas were LA and pigment content. Bozhou had a greater variation in Leaf area and Mudanjiang had a greater variation in pigment content. Bozhou is located in the warm temperate region with higher temperature and precipitation. So this suggested that LA is more sensitive to environmental changes and exhibits greater phenotypic plasticity under such environment. At the time of sampling, plants in Mudanjiang had entered to the autumn, the leaves color was relatively rich so that the pigment content had a wider range of variation. In addition, LT and RWC were relatively stable along the resource axis because the coefficients of variation of the two traits were small at two areas (Pan et al. 2018).

Effects Of Climate On Leaf Morphological Traits

Leaves are the main organ of plants for assimilation and transpiration, and are the most sensitive organ to the environment (Wigly et al. 2016; Wright et al. 2017). Plants have formed their own adaptive traits over the long evolutionary process. Plants traits of different life forms are associated with various abiotic environmental factors such as water and light (Toledo et al. 2011). In general, the lower SLA indicate the strong ability to use environmental resources and to preserve the obtained resources (Delpiano et al. 2020). It is more suitable for arid and barren environments. The larger SLA are likely to have higher light capture capacity and higher the relative growth rate. In this study, SLA of shrub and vine in Mudanjiang were significantly higher than that in Bozhou. That probably due to the lower light intensity in Mudanjiang, which tends to increase plant SLA (Shipleyet al. 2002). In addition, it is speculated that the plants in this area may had a low capacity of environmental resources and a low capacity of the obtained resources (Chen et al. 2016). LDMC is characterized as a relatively stable prediction index on the resource acquisition axis. The higher LDMC reflect that plants are making better use of the environmental resource conditions of the habitat (Bao and Liu 2019). The LDMC of all life forms in Mudanjiang were significantly higher than in Bozhou ($P < 0.05$). Plants LDMC increase with the decrease of temperature (Sun et al. 2017), due to higher LDMC can prevent plants from losing water and nutrients. LDMC was a common indicator of plant leaf water retention. It was an important indicator of plant trait that reflects the ability of plants to withstand drought environment (liu and Guan 2018).The LDMC of trees and shrubs in Bozhou were significantly higher than that of Mudanjiang with an average of 30.09% higher. The average rainfall in Bozhou is 1.5 times higher than that of Mudanjiang. It is possible that more water the leaves absorb, the stronger water retention capacity the leaves have so that the LDMC is significantly larger.

Effects Of Climate On Leaf Physiological Traits

Chlorophyll played a crucial role at photosynthesis and was the basic composition of membrane material in plant organs. It was vital indicator of photosynthetic capacity, nutritional status and growth trend in the growth of plants (Lichtenthaler et al.1996; Wang et al. 2021). Chla was considered to be the central pigment of photosynthesis. The concentration change can be used to monitor plant growth (Raven et al. 1992), and also characterize external interference (Blackburn 2007). Chlb transmited luminous energy to Chla to boost the efficiency of plant utilization of luminous energy. They can serve as accessory pigments (Bidlack and Jansky 2011), with carotenoids which protects the plant from light damage when content of carotenoids rises. In this study, the pigment content of shrubs in Mudanjiang was significantly higher than that in Bozhou. The vine's pigment content in Bozhou was significantly larger than that in Mudanjiang but except Car. The Car in Mudanjiang was 2 times higher than that in Bozhou. It reflected that the plants of different life forms formed their own pigment characteristics in stable growth environment.

Interrelations Of Leaf Traits In Two Areas

In the process of long evolution and adaptation to the environment, plants have formed a series of traits combinations which are the optimal to adapt the environment (Subedi et al. 2016). LES provided a new theory and method for analyzing the adaptation mechanism of plants(Wright et al. 2004). A large number of studies showed that the relationship were negatively between SLA with LDMC and LT. In this study, there was a significant negative correlation between LT and SLA (Bozhou $P < 0.001$, Mudanjiang $P < 0.001$). Garnier et al. (2001) pointed out that the change of LDMC may maintain a certain relative independence for plants with small SLA. Leaves, as the secondary functional units of plants, are relatively stable. So some leaf traits didn't change significantly in response to the light environment. The adaptation strategies of different plantts often vary from species to species. Li et al (2019) study showed that there was a positive relationship between SD and VD, which was similar to the results of our study. VD was positively correlated with SD ($P < 0.1$). The correlation in Mudanjiang was more significant and linear fitting degree in Bozhou was higher. In our study, SD and VD were positively correlated with SLA and negatively correlated with LT under the two climates. It basically confirmed our second hypothesis.

The plants with large LT, their own drought resistance was stronger. It's not necessary to increase the VD to enhance the water supply capacity of leaves compared with thin leaves but also to reduce SD to resist transpiration. The correlations among VD with SLA and LT, SD with SLA and LT were consistent in two cities. It showed that the coordination of plant structure and function had convergence in different environments. Different species have different resource utilization strategies. Principal component analysis showed that PCA1 axis is negatively correlated with LDMC and RWC, positively correlated with pigment content. PCA2 axis is positively correlated with SLA, LDMC and LA, and negatively correlated with Car (Fig. 3). It reflected that there were some differences in the balance strategies of plant leaf traits under different climates, but these balance strategies were smaller difference in pigment. In our study, there were no correlation analysis between leaf traits and climate. It is also the main research direction in the future.

Conclusion

In this study, the differences and relationship of leaf traits were studied. All the leaf traits were based on plants of different life forms in two areas with different water, altitude and light intensity. We found that the leaf traits of 17 species garden plants in Mudanjiang and 9 species garden plants in Bozhou varied in different degrees. The SLA, LDMC, VD and LT of trees, shrubs and vines in Mudanjiang were relatively high, while LA, RWC and SD in Bozhou were higher. The pigment content of shrubs Mudanjiang and vines in Bozhou are higher. The difference of trees was not significant in two areas. It indicated that the sensitive response to climates of different life forms leaf traits was different. There was a certain relationship between morphological traits and pigment content of leaves in the two areas, but also were some differences. The relationships among pigments were closer. It reflected the differences and coordination of the balance strategies of leaf traits.

Declarations

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Author contributions LYX and NNZ designed the research. LYX performed the research. YL, TCW, LYS, and BYL analyzed the data. NNZ, LYX,and DNL wrote and revised the paper.

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Data availability Data are available as the electronic supplementary material.

Code availability Code are available as the electronic supplementary material.

Conflict of interest We have no conflict of interest to declare.

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Figures

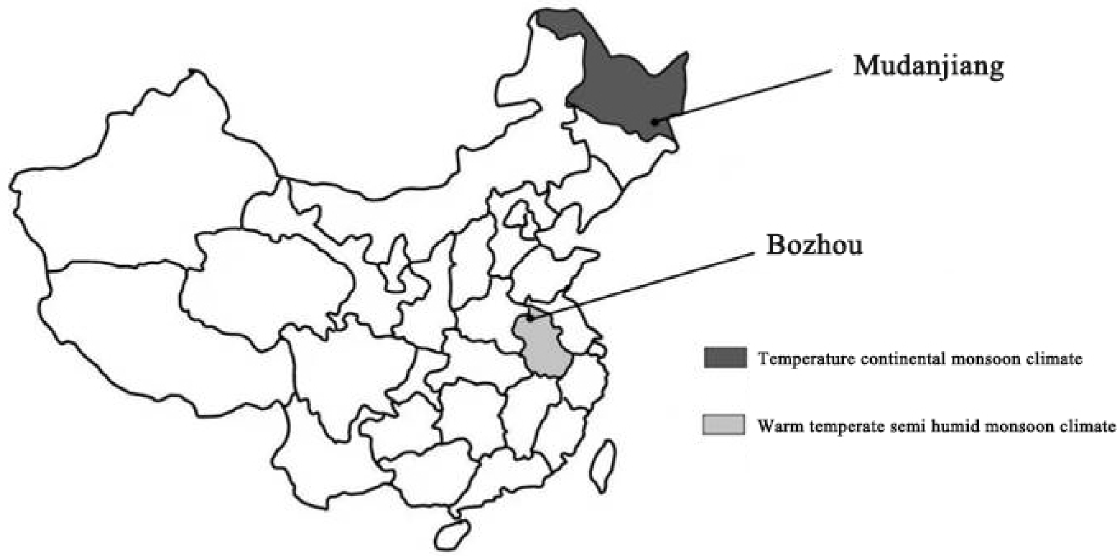

Figure 1

Geographical location of the study area

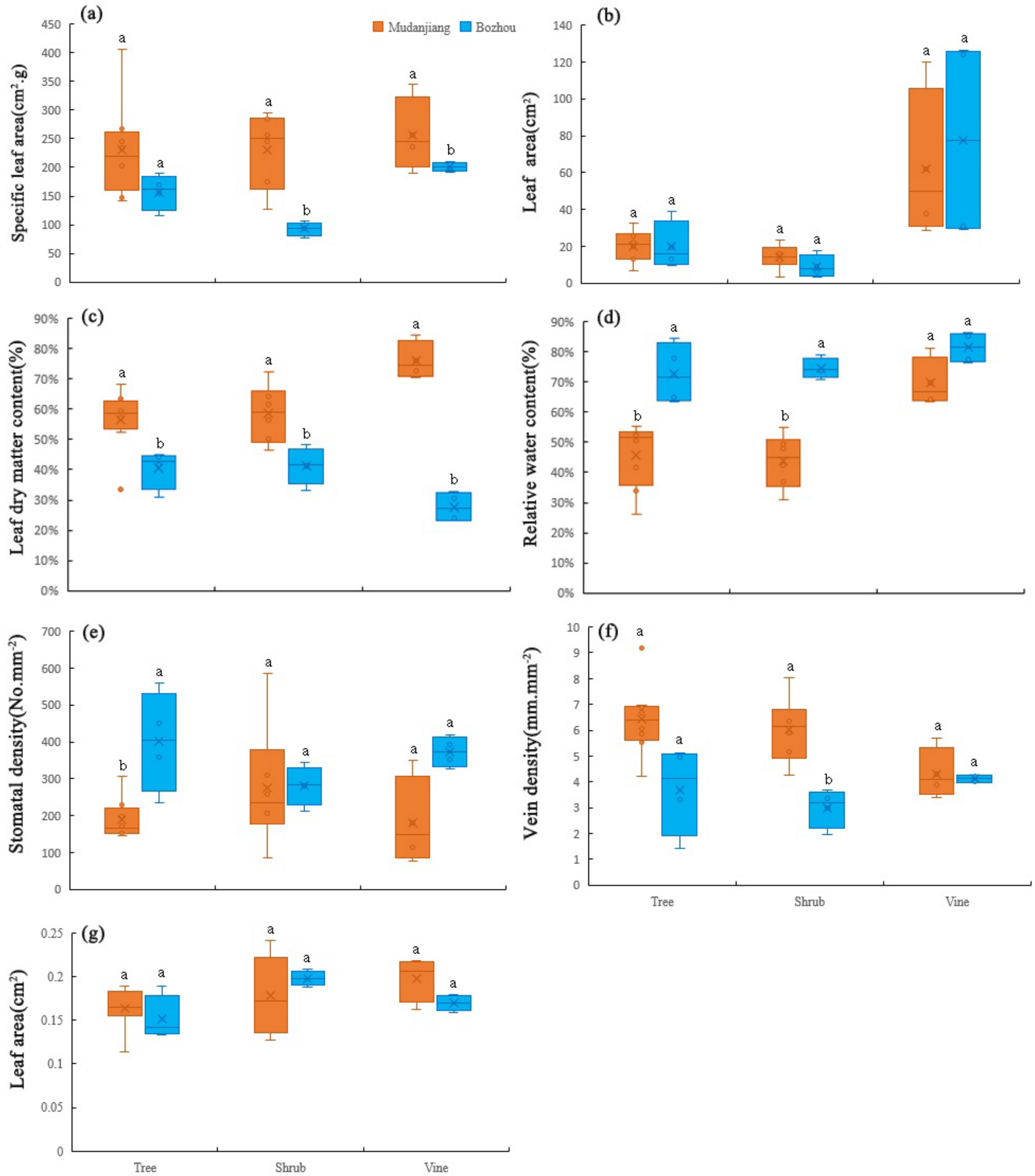

Figure 2

Specific leaf area($cm^2 \cdot g^{-1}$) (a), Leaf area (cm^2) (b), Leaf dry matter content(%)(c); Relative water content(%)(d), Stomatal density(No $\cdot mm^{-2}$) (e), Leaf vein density($mm \cdot mm^{-2}$) (f), Leaf thickness (mm) (g) of tree, shrub and vine in two urbans in China. Different lowercase letters indicate significant differences at P<0.05 levels.

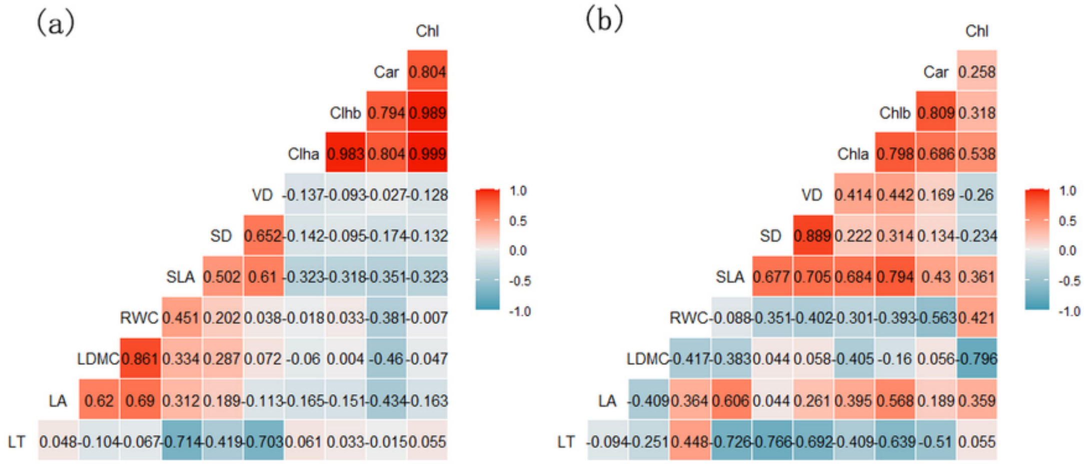

Figure 3

Correlation between plant leaf traits in two urbans in China. Abbreviations: LT: Leaf thickness; LA: Leaf area; LDMC: Leaf dry matter content; RWC: Leaf relative water content; SLA: Specific leaf area; SD: Stomatal density; VD: Leaf vein density; Chla: Chlorophyll a; Chlb: Chlorophyll b; Car: Carotinoid; Chl: Chlorophyll. (a): Mudangjiang;(b): Bozhou.

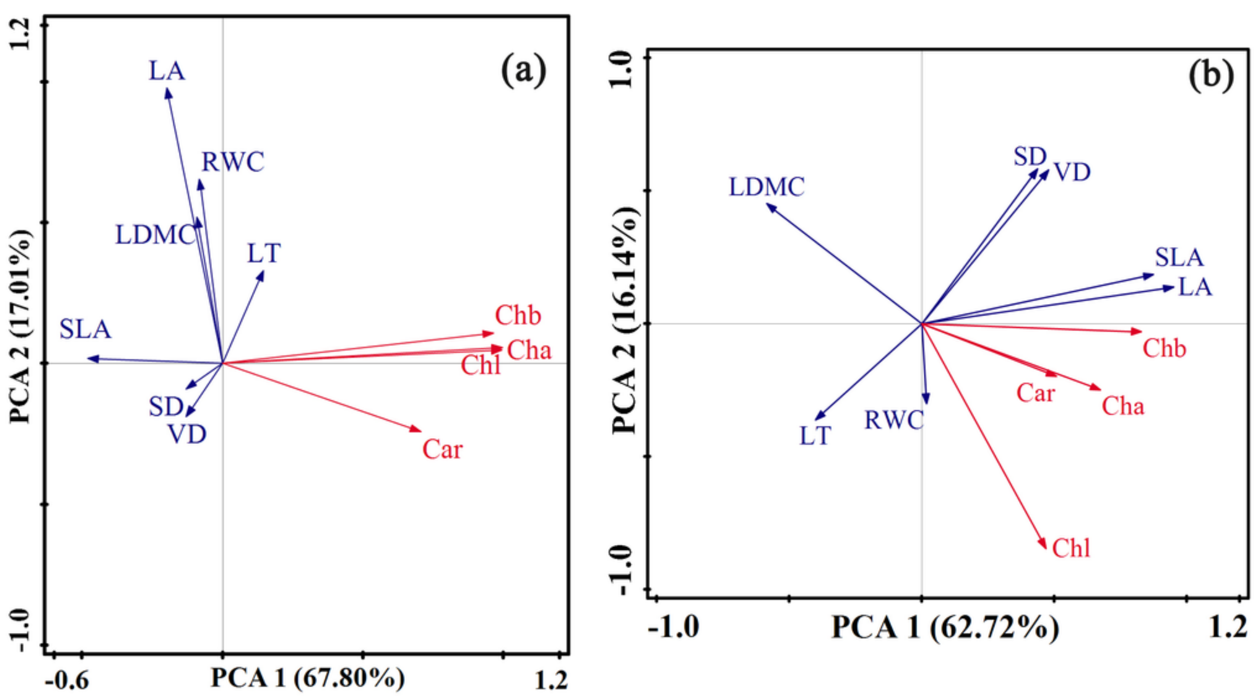

Figure 4

Principal component analysis of species leaf morphological traits (blue lines) and physiological traits (red line) in two urbans in China. Abbreviations: LT: Leaf thickness; LA: Leaf area; LDMC: Leaf dry matter content; RWC: Leaf relative water content; SLA: Specific leaf area; SD: Stomatal density; VD: Leaf vein density; Chla: Chlorophyll a; Chlb: Chlorophyll b; Car: Carotinoid; Chl: Chlorophyll.(a): Mudangjiang;(b): Bozhou.

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