Comprehensive Evaluation of Colored-leaf Plants in Hefei City Based on AHP

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Abstract Based on the investigation of colored-leaf plant resources in Hefei City, analytic hierarchy process (AHP) was used to construct a comprehensive evaluation system for colored-leaf plants in Hefei City. This system is composed of three layers: leaf ornamental value, ecological adaptability, and other ornamental values, including 12 evaluation indicators. The landscape value of the 20 selected species of colored-leaf trees were comprehensively evaluated. The evaluation results show that 9 kinds of colored-leaf trees such as *Ginkgo biloba* and *Triadica sebifera* are excellent (grade I, comprehensive evaluation value > 3.5); 7 species of colored-leaf trees such as *Sophora japonica* and *Albizia julibrissin* are good (grade II, 2.5 ≤ comprehensive evaluation value ≤ 3.5); 4 types of colored-leaf trees such as *Celtis sinensis* and *Pistacia chinensis* are general (grade III, comprehensive evaluation value < 2.5). These results can provide theoretical references for the application of colored-leaf trees in urban green spaces of Hefei City.

Keywords Analytic hierarchy process, Colored-leaf plants, Landscape value, Hefei City
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Colored-leaf plants refer to a group of plants that can stably display non-green leaves during part or all of their growth cycle, including plants whose leaves remain in a non-green state and are not disturbed by external factors such as physiological changes, pests and diseases, and cultivation measures during the growing season[1]. With the acceleration of urbanization, colored-leaf plants have become an indispensable part of modern urban greening and play an important role due to their unique leaf colors, lasting ornamental characteristics and diverse tree shapes[2].

Analytic hierarchy process (AHP) is a multi-level decision-making analysis method that combines qualitative analysis with quantitative analysis[3]. In this study, colored-leaf trees applied in the urban green spaces of Hefei City was as the evaluation object, and AHP was used to construct a comprehensive evaluation system of colored-leaf plants in Hefei City, aiming to provide a scientific basis for the selection and configuration application of colored-leaf tree species in Hefei City.

1 Materials and methods

1.1 General situation of the study area

Hefei City is located in the central part of Anhui Province and between the Yangtze River and the Huaihe River. It has a subtropical monsoon humid climate, with cold and dry winters and hot and rainy summers. It is characterized by abundant sunlight and moderate rainfall. The soil is yellowish-brown soil, and the zonal vegetation is a mixture of deciduous and evergreen broad-leaved forests.

1.2 Research materials

Through on-site research, it is found that 135 species of colored-leaf plants are applied in the urban green spaces of Hefei City. How to scientifically screen out tree species that not only meet the urban greening needs of Hefei City but also have excellent ecological adaptability is an important and complex issue. In this study, through AHP, 20 most representative colored-leaf trees were selected as the evaluation objects of this study.

1.3 Research method

1.3.1 Construction of a comprehensive evaluation system. In this study, highly representative evaluation factors were scientifically measured and screened out by using AHP[5-7]. The data were sorted and analyzed through Excel software, and the visual modeling and calculation assistant software yaahp 10.5 was introduced for calculation at the same time. The selected 20 kinds of colored-leaf trees are as the evaluation objects, and a hierarchical structure comprehensive evaluation system composed of target layer (A), criterion layer (B), indicator layer (C) and scheme layer (D) was established starting from the natural conditions of the city and the current situation of urban greening. Among them, target layer (A) is to conduct a comprehensive evaluation of colored-leaf trees in Hefei City. Criterion layer (B) includes three evaluation factors: leaf ornamental value, ecological adaptability and other ornamental values. Indicator layer (C) has a total of 12 evaluation indicators, namely leaf color, leaf shape, colored-leaf rate, colored-leaf duration, drought resistance, cold resistance, disease resistance, growth vigor, landscape effect, flower viewing, shape viewing and fruit viewing. Scheme layer (D) consists of 20 representative colored-leaf trees to be evaluated. The comprehensive evaluation indicator system of colored-leaf trees in Hefei City is shown in Table 1.

1.3.2 Determination of the quantitative grading standard for colored-leaf trees. Based on the on-site investigation, a new 5-point comprehensive evaluation standard (Table 2) was formulated, which was used as the evaluation basis to conduct a comprehensive assessment of the colored trees in Hefei City.

2 Results and analysis

2.1 Construction of judgment matrices and consistency test

Based on the research purpose and the requirements of establishing an evaluation system for colored-leaf trees, the 1–9 scaling method was adopted to evaluate and quantify the three evaluation factors in the criterion layer and the 12 evaluation indicators in the indicator layer. Finally, four judgment matrices A-B_n, B_1–C_n, B_2–C_n, and B_3–C_n were constructed (Table 3). In this study, the power method and root method were adopted to calculate the eigenvector (W) of each evaluation indicator and its corresponding maximum characteristic root (λ_{max}), thereby determining the relative weight relationships among factors at each level. The consistency test was conducted by calculating the ratio of the consistency index *CI* to the random consistency

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index RI ($CR=CI/RI$). When CR value is less than 0.10, the judgment matrix has good consistency[8]. It can be known from Table 3 that the CR of the four judgment matrices is <0.10, all passing the consistency test.

2.2 Weight of the overall ranking of layers

The ranking of the relative importance of all factors in the same layer to the highest layer (i.e., target layer A) is called the overall ranking of layers[9]. It can be seen from Table 4 that in terms of leaf ornamental value (B_1) in the criterion layer, the weight of leaf color (C_1) is the largest, up to 0.324 1. In terms of ecological adaptability (B_2) in the criterion layer, the weight of growth vigor (C_8) is the largest, reaching 0.136 6. For other ornamental values (B_3), the weight of landscape effect (C_9) reached the maximum (0.063 7). The above results show that leaf color (C_1), growth vigor (C_8) and landscape effect (C_9) are the three core evaluation indicators that determine the urban greening landscape value of colored-leaf trees.

2.3 Grading of evaluated colored-leaf plants based on the evaluation results

Firstly, the 12 specific evaluation indicators of colored-leaf trees were scored through the expert assignment method, and the average was taken. Based on the comprehensive evaluation value, the final score of each indicator for each type of colored-leaf trees was obtained. Then, weighted calculation was carried out based on the weight of each evaluation indicator itself

Table 1 Comprehensive evaluation indicator system of colored-leaf trees in Hefei City

Target layer (A)	Criterion layer (B)	Indicator layer (C)	Scheme layer (D)
Comprehensive evaluation of colored-leaf trees in Hefei City A	Leaf ornamental value B_1	Leaf color C_1, leaf shape C_2, colored-leaf rate C_3, and colored-leaf duration C_4	Colored-leaf trees to be evaluated D_1, D_2, D_3, $\cdots$, D_{20}
	Ecological adaptability B_2	Drought resistance C_5, cold resistance C_6, disease resistance C_7, and growth vigor C_8	
	Other ornamental values B_3	Landscape effect C_9, flower viewing C_{10}, shape viewing C_{11}, fruit viewing C_{12}	

Table 2 Specific evaluation standard for the indicator layer of colored-leaf trees in Hefei City

Evaluation indicator	Evaluation standard		
	5	3	1
Leaf color	Bright and vivid	Light and bright	Natural green
Leaf shape	Peculiar and beautiful	More beautiful	General
Colored-leaf rate	80% and above	50% and above	Less than 50%
Colored-leaf duration	3 seasons and above	2 seasons	1 season and below
Drought resistance	Tolerating long-term arid environments	Irrigation is needed in case of long-term drought	Frequent watering is needed
Cold resistance	Surviving the winter normally and having no frost damage	Less than 30% of branches and tips are frozen and withered	More than 30% of branches and tips are frozen and withered
Disease resistance	The plants grow healthily	The plants have diseases, but their growth is not affected	They are prone to diseases, and their growth is affected
Growth vigor	Good	General	Bad
Landscape effect	The effect is excellent, and they can be enjoyed all year round	They are of ornamental value most of the time	Only their leaves can be viewed
Flower viewing	The flowers are large or numerous	The flowers are medium in size or quantity	The flowers are small or scarce
Shape viewing	The trees have an elegant posture and can be planted alone	The tree canopy is relatively neat and has ornamental value	The tree shapes are disordered and have no ornamental value
Fruit viewing	The fruits are abundant in quality and bright in color	The fruits are medium in quantity and light and bright in color	The fruits have no obvious ornamental value

Table 3 Judgment matrices and consistency test

Hierarchical model	Judgment matrix					Relative weight (W)	Consistency test
A-B_n	A Comprehensive evaluation	B_1	B_2	B_3			λ_{max}=3.038 7 CI=0.019 4 CR=0.037 2<0.10
	B_1 Leaf ornamental value	1	3	5		0.633 3	
	B_2 Ecological adaptability	1/3	1	3		0.260 5	
	B_3 Other ornamental values	1/5	1/3	1		0.106 2	
B_1-C_n	B_1 Leaf ornamental value	C_1	C_2	C_3	C_4		λ_{max}=4.105 0 CI=0.035 0 CR=0.039 3<0.10
	C_1 Leaf color	1	3	5	3	0.511 7	
	C_2 Leaf shape	1/3	1	3	1/2	0.172 5	
	C_3 Colored-leaf rate	1/5	1/3	1	1/3	0.078 0	
	C_4 Colored-leaf duration	1/3	2	3	1	0.237 8	
B_2-C_n	B_2 Ecological adaptability	C_5	C_6	C_7	C_8		λ_{max}=4.065 2 CI=0.021 7 CR=0.024 4<0.10
	C_5 Drought resistance	1	2	2	1/3	0.221 6	
	C_6 Cold resistance	1/2	1	1/2	1/5	0.096 0	
	C_7 Disease resistance	1/2	2	1	1/3	0.158 1	
	C_8 Growth vigor	3	5	3	1	0.524 3	
B_3-C_n	B_3 Other ornamental values	C_9	C_{10}	C_{11}	C_{12}		λ_{max}=4.144 1 CI=0.048 0 CR=0.054 0<0.10
	C_9 Landscape effect	1	5	5	5	0.599 9	
	C_{10} Flower viewing	1/5	1	2	3	0.194 8	
	C_{11} Shape viewing	1/5	1/2	1	2	0.124 4	
	C_{12} Fruit viewing	1/5	1/3	1/2	1	0.080 9	

and the corresponding score of each indicator to obtain the comprehensive evaluation score A of the 20 kinds of colored-leaf trees. The calculation formula of the comprehensive score is as follows: $A=\sum_{i=1}W_iX_i$, where W_i is the total ranking weight of each evaluation indicator; X_i is the score of each evaluation indicator[10]. Finally, the 20 types of colored-leaf trees participating in the evaluation were classified into three grades based on the comprehensive score: grade I (excellent grade, $A > 3.5$) indicates that the colored-leaf trees have a high utilization value; grade II (good grade, $2.5 \leqslant A \leqslant 3.5$) has relatively high utilization value; grade III (general grade, $A < 2.5$) means the utilization value of the colored-leaf trees is medium (Table 5).

2.4 Analysis of the comprehensive evaluation results of landscape value

As shown in Table 5, among the selected 20 species of colored-leaf trees, 9 species of colored-leaf trees with a high utilization value were rated as grade I. Seven kinds of colored-leaf trees with a relatively high utilization value were rated as grade II. Four types of colored-leaf trees with an average utilization value were rated as grade III.

Excellent tree species (grade I) include nine species such as *G. biloba*, *T. sebifera*, and *L. chinense*. These tree species have the characteristics of bright leaf color, high color lightness, long colored-leaf duration, and strong ecological adaptability. In addition, their flowers, fruits and tree shapes all have high ornamental value. They can be widely promoted and applied in urban green spaces. Good tree species (grade II) contain seven species, such as *S. japonica*, *M. azedarach*, and *U. pumila*. These tree species have relatively light and bright leaves, with general color lightness and saturation, and their leaves are mostly yellow or green. Although their landscape effect is relatively average, they still have certain ornamental value, and their score is relatively high in the three evaluation factors of the criterion layer. They are recommended for use in suitable green spaces. General tree species (grade III) include four species, such as *C. sinensis* and *P. chinensis*. Their leaves are mostly natural green, and their colored-leaf duration is relatively short. They do not have high landscape appreciation value and have low comprehensive application value in urban green spaces.They should not be applied widely.

3 Conclusions and discussion

Based on AHP, 20 species of the most representative colored-leaf trees were as the evaluation objects to construct a comprehensive evaluation system for colored-leaf plants in Hefei City. The study aims to optimize the structure of colored-leaf trees in urban green spaces of Hefei City and provide decision support for urban greening construction. The research results show that tree species with a high score can be widely promoted and applied. For tree species with a low score, it is needed to optimize their growth environment and strengthen their maintenance and management to improve their application effect in urban green Spaces.

From the weight of the 12 evaluation indicators set in this comprehensive assessment, leaf color (C_1), colored-leaf duration (C_4), growth vigor (C_8), leaf shape (C_2), landscape effect (C_9), and drought resistance (C_5) have become the main indicators for evaluating colored-leaf trees. These indicators not only reflect the biological characteristics and ornamental value of the colored-leaf trees themselves, but also highlight their practical application effects in urban landscape construction. From the perspective of weight distribution, leaf color (C_1) and colored-leaf duration (C_4) rank first and second respectively. This weight distribution fully indicates that in the configuration process of colored-leaf trees, it is necessary not only to pay attention to the aesthetic combination of leaf colors, but also to consider the time sustainability of maintaining the ornamental effect of colored-leaf trees throughout the year cycle. This dual consideration is conducive to creating urban landscapes that not only conform to aesthetic laws but also have ecological implications, thereby achieving the sustainable development and ecological harmony of urban landscapes. Growth vigor (C_8) and leaf shape (C_2) rank third and fourth respectively with weight values of 0.136 6 and 0.109 2. Growth vigor reflects the growth status and climate adaptability of colored-leaf trees, while leaf shape embodies the morphological characteristics of plants. Together, they provide an important basis for the cultivation management and landscape application of colored-leaf trees. In practical applications, more attention should be paid to the growth status and climate adaptability of colored-leaf trees. The weight values of landscape effect (C_9) and drought resistance (C_5) rank fifth and sixth. Landscape effect refers to the overall performance of colored-leaf trees in garden landscapes and is an important basis for evaluating whether colored-leaf trees are suitable for garden landscapes. The weight of drought resistance is relatively high, meaning that when colored-leaf trees are bred and applied, varieties that can adapt to drought environments

Table 4 Weight of the overall ranking of various layers in the comprehensive evaluation

Evaluation indicator	B_1 (W_{B1}=0.633 3)				B_2 (W_{B2}=0.260 5)				B_3 (W_{B3}=0.106 2)			
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Weight	0.511 7	0.172 5	0.078 0	0.237 8	0.221 6	0.096 0	0.158 1	0.524 3	0.599 9	0.194 8	0.124 4	0.080 9
Total weight	0.324 1	0.109 2	0.049 4	0.150 6	0.057 7	0.025 0	0.041 2	0.136 6	0.063 7	0.020 7	0.013 2	0.008 6

Table 5 Comprehensive evaluation score and grade of colored-leaf trees in Hefei City

Plant name	Score	Grade	Plant name	Score	Grade
Ginkgo biloba	3.990 8	I	*Albizia julibrissin*	3.434 9	II
Triadica sebifera	3.987 6	I	*Melia azedarach*	3.406 8	II
Liriodendron chinense	3.976 5	I	*Ulmus pumila*	2.984 7	II
Liquidambar formosana	3.825 2	I	*Metasequoia glyptostroboides*	2.953 4	II
Cotinus coggygria	3.815 6	I	*Taxodium distichum*	2.639 4	II
Acer buergerianum	3.710 4	I	*Bischofia polycarpa*	2.585 9	II
Koelreuteria paniculata	3.614 8	I	*Celtis sinensis*	2.416 6	III
Sapindus mukurossi	3.544 4	I	*Pistacia chinensis*	2.414 9	III
Platanus×acerifolia	3.532 8	I	*Ulmus parvifolia*	2.387 7	III
Sophora japonica	3.474 6	II	*Toona sinensis*	2.377 5	III

(To be continued in P64)

can be abstractly translated into geometric patterns and integrated into creative products such as refrigerator magnets, bookmarks, tea sets, folding fans, keychains, notebooks, and clothing. This approach retains the cultural core while catering to the aesthetic preferences of young people. Digital collections can also be designed in combination with garden artifacts and Cantonese opera performances, and unique script-killing scripts based on Liang Garden stories can be developed.

3.3.3 Promoting museumization of idle functional spaces. Museumization of garden space is an effective way to reasonably utilize idle garden space resources and increase educational participation spaces[8], enhancing the dissemination and educational functions of garden historical and cultural heritage. In some idle spaces of Liang Garden, suitable venues can be selected to establish a special exhibition hall for Lingnan garden-making techniques. Interactive technology can be used to display traditional Lingnan garden-making techniques such as rock stacking and water management, and digital sand tables can be introduced to dynamically demonstrate the historical evolution of Liang Garden's landscape space.

3.3.4 Inheriting and disseminating through cultural and educational activities. The dynamic utilization and cultural inheritance of garden space can be continuously ensured through cultural and educational activities. Students from nearby primary and secondary schools can be organized to conduct educational tours in Liang Garden, forming a complete educational route in combination with surrounding scenic spots. At the same time, regular Cantonese opera performances, tea art appreciation, and poetry creation activities can be held to attract local residents and visitors, achieving the goals of cultural education and dissemination.

4 Conclusion

Lingnan classical gardens, as an important part of Chinese classical gardens, have their own unique gardening characteristics and distinct features. Foshan Liang Garden, as one of the four famous gardens in Lingnan, has achieved a high level of gardening art and possesses significant artistic, cultural, and scientific value. However, during the current protection and utilization of Foshan Liang Garden, several issues have emerged, including insufficient protection funding, outdated protection methods, unreasonable resource protection, and singular means of protection and utilization. These problems are also common in many historical gardens. This study has proposed corresponding protection and revitalization strategies for these issues, emphasizing the basic principle of emphasizing both protection and revitalization and implementing them simultaneously. It adopts methods of protection and utilization such as expanding funding channels, strengthening dynamic monitoring and scientific protection, exploring cultural connotations, and encouraging multi-stakeholder participation in joint construction. It also implements revitalization strategies such as empowering garden services with digital technology, innovating cultural and creative products by integrating cultural resources, promoting museumization of idle functional spaces, and inheriting and disseminating through cultural and educational activities. These methods and approaches can provide valuable experience and reference for the sustainable development of similar historical gardens.

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should be selected to reduce maintenance costs and water resource consumption. The weight distribution of these two indicators provides clear directional guidance for the breeding and cultivation practice of colored-leaf trees, and has important reference value for promoting the scientific application of colored-leaf trees.

Although AHP is systematic and practical, it is highly subjective. Especially in the application of the 1-9 scale method, the evaluation results are easily influenced by experts' experience. Furthermore, the comprehensive evaluation indicator system constructed in this study also has limitations. For instance, ecological adaptability indicators such as salt and alkali tolerance and annual growth have not been fully incorporated, which requires further in-depth exploration.

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