RESEARCH ARTICLE

Physiological response and comprehensive evaluation of 12 plant species to multiple stresses in sponge city construction

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Received: October 9, 2024; **accepted:** January 7, 2025.

With the rapid urbanization of the global population, cities are increasingly confronted with challenges such as floods, the urban heat island effect, and surface water discharge. Traditional approaches to urban design and construction often struggle to effectively address these challenges. Hence, the concept of a sponge city has emerged as an innovative strategy for mitigating urban environmental problems. The concept of a sponge city is a new urban planning and design, aimed at enhancing the ecosystem service capacity of cities by emulating the functions of natural ecosystems. In this study, 12 common garden plants in Xinyang, Henan, China were selected to carry out drought and flooding tolerance stress tests. The investigation involved the detection and analysis of 5 physiological indexes of soluble sugars (SS), soluble protein (SP), malondialdehyde (MDA), superoxide dismutase (SOD) and peroxidase (POD) of the 12 plants under drought and flooding stress. Utilizing a comprehensive evaluation of the affiliation function, the results indicated that the ability of the 12 plants to resist the drought-flooding compound stress was ranked as *Mentha canadensis* L. > *Muhlenbergia capillaris* Trin. > *Hypericum patulum* Thunb. > *Ruellia simplex* C. Wright > *Trachelospermum jasminoides* (Lindl.) Lem. > *Artemisia argyi* H. Lév. & Vaniot > *Lonicera japonica* Thunb. > *Echinacea purpurea* (L.) Moench > *Sedum lineare* Thunb. > *Euonymus fortunei* (Turcz.) Hand. -Mazz. > *Pyracantha fortuneana* (Maxim.) H. L. Li > *Houttuynia cordata* Thunb. Among them, *Mentha canadensis* L., *Muhlenbergia capillaris* Trin., *Hypericum patulum* Thunb., *Ruellia simplex* C. Wright belonged to comprehensive strong-drought-tolerant and strong-flood-tolerant plants, which were suitable for planting in the buffer zone of the sunken green belt and rain garden in sponge city. *Artemisia argyi* H. Lév. & Vaniot., *Euonymus fortunei* (Turcz.) Hand.-Mazz., and *Houttuynia cordata* Thunb. belonged to strong-drought-tolerant and weak-flood-tolerant plants, appropriate for planting in the ditches of the rainwater transmission facilities, as well as in the edge zones of the sunken green belt and rain gardens. Additionally, *Trachelospermum jasminoides* (Lindl.) Lem., *Lonicera japonica* Thunb., *Echinacea purpurea* (L.) Moench, *Sedum lineare* Thunb., and *Pyracantha fortuneana* (Maxim.) H. L. Li were strong-flood-tolerant and weak-drought-tolerant plants, which were suitable for planting in the water retention area of the sunken green belt and rain gardens. This study conducted a comprehensive exploration regarding the application of garden plants in the construction of a sponge city with the purpose of better exploiting the absorption, infiltration, and slow-release functions of plant ecosystems in urban rainwater management, while also investigating innovative strategies for sustainable urban development.

Keywords: sponge city; landscape plants; drought stress; flooding stress; stress tolerance.

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Introduction

Sponge city is a kind of urban construction model that solves urban water problems through the system of accumulation, infiltration, purification [1]. The core objective of constructing a sponge city lies in modifying the land use and cover forms of ecological infrastructures such as green roofs on rooftops and sunken green spaces on the ground [2]. The sponge city concept represents an innovative approach to urban development and management, employing diverse technologies to establish a sustainable urban water cycle, facilitating the effective absorption, storage, infiltration, and purification of rainwater, thereby strengthening the urban water cycle system. The design of sponge cities is intended to mitigate flood risks, enhance the efficiency of water resources, and improve the urban ecological environment. Specifically, sponge cities promote natural rainwater management through the adoption of green infrastructure and low-impact development (LID) strategies. These measures significantly improve the urban ecological environment by increasing green space coverage, reducing the urban heat island effect, and enhancing air quality, ultimately leading to a higher quality of life for residents.

Currently, urban water ecology in China faces two significant challenges including severe urban flooding that tests the effectiveness of urban flood management and widespread water scarcity that characterizes by inadequate water supply in numerous cities. These issues originate from a common underlying cause of the lack of synchronization in urban water ecology that hinders the natural regulation of water cycle. Constructing cities that facilitate natural water cycling, regulation, and infiltration is essential for enhancing urban drainage capabilities and restoring urban water ecosystems. However, in the ongoing development of sponge cities, the selection and integration of plants based on urban water ecological considerations are frequently neglected. Plants play a vital role in sponge city design as they contribute to rainwater retention, reduce the velocity of surface runoff and peak runoff levels, promote soil infiltration, and mitigate pollutants in runoff. [3]. According to the requirements of sponge city in the construction of green space, the planted garden plants should give full play to the role of the "sponge". In heavy rainfall, these plants must not only sustain their normal biological activities but also serve as rain-collecting green spaces that effectively store and absorb water, while during dry periods, they should be capable of withstanding drought conditions within the urban planting environment. Drought significantly impacts the normal growth and metabolic development of plants, making it one of the most destructive environmental stresses [4]. Since plant growth and metabolism are closely linked to water availability, plants exhibit physiological changes in response to drought conditions [5, 6]. In recent years, global climate anomalies have led to frequent localized heavy rainfall and flooding, resulting in urban flooding becoming increasingly common. Different plants have different water requirements and vary in their ability to tolerate flooding stress. Flooding can lead to excessive soil moisture content, which can cause severe hypoxia in plant root tissues and impeded aerobic respiration, resulting in poor plant growth or even death [7, 8]. In sponge city construction, plants as the main component of sponge facilities play an important role in slowing down the flow rate, infiltration, absorbing pollutants, improving landscape benefits, and regulating microclimate [9]. Therefore, it is necessary to consider not only the landscape effect of plants, but also the drought tolerance and flood tolerance ability of plants. For example, the selection of plants in the grass ditch should especially consider the drought tolerance of plants to resist the dry environment of the grass ditch in the non-rainy season period. However, for the sunken green belt and rain garden water storage area, only the plants that have enough flooding tolerance should be planted to ensure that they can effectively infiltrate and absorb the rainwater. Exposure to drought and flooding stress significantly alters the physiological indices of soluble protein (SP), soluble sugar (SS), malondialdehyde (MDA), superoxide dismutase (SOD), and peroxidase (POD) in the plants [10-12]. There are considerable differences in drought and flooding tolerance among various plant species, attributed to their unique biological characteristics. Comparison of these physiological response changes among different plants can effectively reflect the degree of drought and flooding tolerance, making these indices valuable for evaluating the resilience of various plant species to such environmental stresses.

Xinyang, Henan, China is in the upper reaches of the Huaihe River and the northern foot of the Dabie Mountains. It has a dense river network and abundant water resources. The city experiences substantial annual average rainfall of approximately 1,105 mL, the highest place in the Henan province. However, urbanization and economic development have resulted in a continuous decline in water quality, exacerbating urban flooding during the rainy season. Consequently, the implementation of sponge city construction and the establishment of a LID rainwater system are essential measures that can significantly enhance the ecological civilization of Xinyang. This research took 12 common garden plants as test subjects in the urban construction of Xinyang, which included shrubs, ground covers, and herbs, to study their physiological responses under drought and flooding stress to comprehensive comparison of their tolerance to these conditions. By quantitatively ranking various indices, the research identified several plants that were commonly used in Xinyang with excellent landscape and ornamental qualities. Additionally, the study analyzed the utilization of the selected plants in the later stage of the sponge facilities to provide reference standards for local sponge city construction. Furthermore, the research explored how the chosen plants could be effectively utilized in different sponge facilities, thereby establishing a foundation for future urban planning in the region.

Materials and methods

Research materials and experimental design

The seedlings of 12 garden plants commonly used in sponge city construction in Xinyang were purchased from Xinyang Lvzhiyuan Flower Market (Xinyang, Henan, China) and network platform (www.taobao.com), which included *Lonicera japonica* Thunb., *Pyracantha fortuneana* (Maxim.) H. L. Li, *Hypericum patulum* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Sedum lineare* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz, *Mentha canadensis* L., *Artemisia argyi* H. Lév. & Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, *Echinacea purpurea* (L.), and *Muhlenbergia capillaris* Trin. The experiment was conducted in the greenhouse of the experimental and training base at Xinyang Agriculture and Forestry University (Xinyang, Henan, China) in late August 2024 with the strictly controlled environment of 20 - 25°C, a relative humidity of 40 - 60%, a minimum of 6 h of light exposure daily. Healthy robust plants with consistent growth patterns and free from pests and diseases were selected and transplanted into individual plastic pots with the growing medium prepared by mixing nutrient soil, river sand, perlite, and coconut coir in a ratio of 6:2:1:1. A total of 108 pots were included in this research and divided into 3 treatment groups as control, drought, and flood with 3 repeats of each plant in each group. The plants of the control group were irrigated every 3 - 4 days based on the moisture content of the substrate to ensure that the water thoroughly saturated the soil. The drought treatment received no irrigation throughout the experiment. The plants of flooding treatment along with their pots were placed inside of two layers of plastic bags with the water being gradually added until the root collar was submerged, and the water level was consistently maintained at this height throughout the experiment. The entire experiment lasted for 30 days, and samples were collected from each plant upon completion.

Measurements of indicators

Five physiological indexes were measured in this study including soluble protein (SP), soluble sugar (SS), malondialdehyde (MDA), superoxide dismutase (SOD), and peroxidase (POD). The SP content was determined using the Caumas Brilliant Blue staining method by measuring the absorbance of Caumas Brilliant Blue (Macklin, Shanghai, China) at a wavelength of 595 nm after its binding with proteins using a Jingke 722N spectrophotometer (Shanghai Jingke, Shanghai, China). The SS content was determined using the anthrone sulfate colorimetric method. The colorimetric quantification of soluble sugars was measured using Jingke 722N spectrophotometer at a wavelength of 630 nm after the colored substances were generated through the reaction of carbohydrates with anthrone (Macklin, Shanghai, China). The MDA content was determined using the thiobarbituric acid method by means of the reaction of MDA with thiosemicarbazide (Macklin, Shanghai, China) under high temperature and acidic conditions. The absorbance values were obtained at wavelengths of 532 nm and 600 nm, respectively, to deduce the content of MDA. The SOD activity was determined using the nitrogen blue tetrazolium photochemical reduction method. The photochemical reaction between riboflavin (Fuchen, Tianjin, China) and nitroblue tetrazolium (Phygene, Fujian, China) was performed, and the activity and content of SOD were detected using a spectrophotometer at a wavelength of 560 nm. The POD activity was determined using the guaiacol method with the reaction between guaiacol (Zhonglian, Tianjin, China) and hydrogen peroxide (Zhihui, Guangzhou, China). The activity and content of POD were detected at a wavelength of 470 nm [13].

Data analysis

The affiliation function method is a widely used mathematical evaluation method, which utilizes the affiliation function for comprehensive evaluation according to the principle of fuzzy mathematics. The specific value of the affiliation function of each physiological index was first found out, and then the values of each affiliation function were summed up. The average value of the affiliation function was eventually obtained using the following calculation method.

$$\mu(X_i) = (X_i - X_{imin})/(X_{imax} - X_{i\,min}) \quad (1)$$

$$\mu(X_i) = 1 - (X_i - X_{i\mathrm{min}})/(X_{i\mathrm{max}} - X_{i\mathrm{min}}) \quad (2)$$

$$X_i = \sum\mu(X_i)/n \quad (3)$$

where X_i was the measured value of indicator *i*. $X_{i\,min}$ and X_{imax} were the minimum and maximum values of indicators for the 12 plant species, respectively. $\mu(X_i)$ was the value of the affiliation function of the indicator X_i. Equation (1) was used if the measured indexes were positively correlated with stress tolerance, while, if negatively correlated, equation (2) would be used. The mean value of the affiliation function was calculated according to equation (3), where the larger the value, the stronger the stress tolerance.

Statistical analysis

Microsoft Excel 2021 (Microsoft, Redmond, WA, USA) was used for data recording and graphing. Statistical analysis was performed using SPSSAU (IBM, Armonk, NY, USA). All data were processed using one-way analysis of variance (ANOVA) with *P* value less than 0.05 as significant differences and *P* value less than 0.01 as highly significant differences.

Results

Effects of drought stress on physiological indicators of 12 plant species

(1) Soluble sugar (SS)

The SS of all 12 plants changed after 30 days of drought stress compared to that of the control group with the highly significant difference ($P < 0.01$) for *Lonicera japonica* Thunb., *Sedum lineare* Thunb., *Mentha canadensis* L., *Hypericum patulum* Thunb., *Artemisia argyi* H. Lév. & Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, and the

Table 1. Effect of drought stress on SS of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Drought stress		
Lonicera japonica Thunb.	13.55 ± 1.08	22.31 ± 2.73	26.681	0.007**
Pyracantha fortuneana (Maxim.) H. L. Li	10.91 ± 1.05	12.41 ± 1.24	2.520	0.188
Trachelospermum jasminoides (Lindl.) Lem.	19.36 ± 0.72	27.09 ± 3.29	15.815	0.016*
Sedum lineare Thunb.	11.03 ± 0.45	5.45 ± 0.51	202.669	0.000**
Mentha canadensis L.	62.09 ± 4.20	28.95 ± 1.35	169.671	0.000**
Hypericum patulum Thunb.	10.17 ± 0.98	37.82 ± 0.66	1,643.962	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	20.28 ± 1.48	14.56 ± 1.58	20.951	0.010*
Artemisia argyi H. Lév. & Vaniot	12.72 ± 1.40	30.62 ± 2.21	139.930	0.000**
Houttuynia cordata Thunb.	53.69 ± 3.21	13.76 ± 0.26	459.778	0.000**
Ruellia simplex C. Wright	5.57 ± 0.13	4.27 ± 0.21	83.011	0.001**
Echinacea purpurea (L.) Moench	21.27 ± 1.07	12.08 ± 0.21	213.011	0.000**
Muhlenbergia capillaris Trin.	3.84 ± 0.19	3.70 ± 0.37	0.331	0.596

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

Table 2. Effect of drought stress on SP of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Drought stress		
Lonicera japonica Thunb.	523.63 ± 126.62	104.80 ± 3.50	32.798	0.005**
Pyracantha fortuneana (Maxim.) H. L. Li	204.30 ± 29.46	124.80 ± 7.50	20.515	0.011*
Trachelospermum jasminoides (Lindl.) Lem.	267.63 ± 31.09	329.97 ± 2.08	12.009	0.026*
Sedum lineare Thunb.	78.97 ± 5.51	50.97 ± 7.57	26.829	0.007**
Mentha canadensis L.	348.97 ± 48.76	108.63 ± 3.79	72.452	0.001**
Hypericum patulum Thunb.	186.07 ± 6.45	52.67 ± 2.51	1,113.460	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	107.77 ± 6.22	62.43 ± 3.10	127.708	0.000**
Artemisia argyi H. Lév. & Vaniot	171.23 ± 1.22	35.47 ± 0.47	32,212.289	0.000**
Houttuynia cordata Thunb.	97.20 ± 6.22	132.43 ± 4.31	64.979	0.001**
Ruellia simplex C. Wright	75.87 ± 3.71	92.87 ± 1.99	49.020	0.002**
Echinacea purpurea (L.) Moench	101.27 ± 2.45	68.53 ± 2.06	313.703	0.000**
Muhlenbergia capillaris Trin.	112.93 ± 2.41	758.73 ± 8.56	15,824.278	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

significant difference ($P < 0.05$) for *Trachelospermum jasminoides* (Lindl.) Lem. and *Euonymus fortunei* (Turcz.) Hand.-Mazz., while no significant difference for *Pyracantha fortuneana* (Maxim.) H.L.Li and *Muhlenbergia capillaris* Trin. (Table 1).

(2) Soluble protein (SP)

The SP of the 12 plants exhibited significant changes after experiencing 30 days of drought stress compared to that of control group. Specifically, the differences of SP compared to the control group were highly significant for *Lonicera japonica* Thunb., *Sedum lineare* Thunb., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, and *Muhlenbergia capillaris* Trin. ($P < 0.01$), while the differences for *Pyracantha fortuneana* (Maxim.) H. L. Li and *Trachelospermum jasminoides* (Lindl.) Lem. were significant ($P < 0.05$) (Table 2).

(3) Malondialdehyde (MDA)

The MDA of all 12 plants changed after

Table 3. Effect of drought stress on MDA of 12 plant species.

Species	Value (mean ± SD)		F	P
	Control	Drought stress		
Lonicera japonica Thunb.	257.98 ± 40.01	179.70 ± 39.42	5.828	0.073
Pyracantha fortuneana (Maxim.) H. L. Li	10.24 ± 2.98	66.57 ± 1.29	902.833	0.000**
Trachelospermum jasminoides (Lindl.) Lem.	218.41 ± 64.12	289.81 ± 19.48	3.405	0.139
Sedum lineare Thunb.	9.38 ± 2.98	66.15 ± 6.49	189.391	0.000**
Mentha canadensis L.	151.31 ± 55.49	44.65 ± 7.74	10.874	0.030*
Hypericum patulum Thunb.	826.91 ± 17.18	227.08 ± 2.82	3,559.246	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	271.58 ± 1.16	263.64 ± 2.11	32.669	0.005**
Artemisia argyi H. Lév. & Vaniot	152.75 ± 13.86	157.99 ± 4.47	0.388	0.567
Houttuynia cordata Thunb.	104.07 ± 1.90	163.03 ± 2.52	1,045.171	0.000**
Ruellia simplex C. Wright	36.64 ± 2.95	36.75 ± 2.44	0.002	0.963
Echinacea purpurea (L.) Moench	177.57 ± 2.83	217.60 ± 0.39	587.414	0.000**
Muhlenbergia capillaris Trin.	103.67 ± 2.16	21.39 ± 1.07	3,498.808	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

experiencing 30 days of drought stress compared to that of control group. Specifically, the differences in MDA compared with control group were highly significant for *Pyracantha fortuneana* (Maxim.) H. L. Li, *Sedum lineare* Thunb., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Houttuynia cordata* Thunb., *Echinacea purpurea* (L.) Moench, *Muhlenbergia capillaris* Trin. (P < 0.01), and significant for *Mentha canadensis* L. (P < 0.05). However, there were no significant differences for *Lonicera japonica* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Artemisia argyi* H. Lév. & Vaniot, and *Ruellia simplex* C. Wright (Table 3).

(4) Superoxide dismutase (SOD)

The SOD of all 12 plants changed when they experienced 30 days of drought stress compared to that of control group. The differences between the control group and *Lonicera japonica* Thunb., *Pyracantha fortuneana* (Maxim.) H. L. Li, *Trachelospermum jasminoides* (Lindl.) Lem., *Sedum lineare* Thunb., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, and *Muhlenbergia capillaris* Trin. were highly significant (P < 0.01), while only *Mentha canadensis* L. showed no significant difference in SOD compared to the control group (Table 4).

(5) Peroxidase (POD)

The POD of all 12 plants changed under 30 days of drought stress compared to that of control group. The differences in POD were highly significant in *Lonicera japonica* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, *Muhlenbergia capillaris* Trin (P < 0.01), and significant in *Sedum lineare* Thunb (P < 0.05) compared to control group. There were no significant differences in POD between the control group and *Pyracantha fortuneana* (Maxim.) H. L. Li and *Mentha canadensis* L (Table 5).

Comprehensive evaluation of drought tolerance of 12 plant species

The physiological responses of plants to drought stress resulted from the combined action of various drought-tolerant mechanisms. Plant drought resistance mechanisms have not yet been systematically and comprehensively understood, and the use of a single indicator to

Table 4. Effect of drought stress on SOD of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Drought stress		
Lonicera japonica Thunb.	1,410.24 ± 39.18	1,102.36 ± 24.02	134.640	0.000**
Pyracantha fortuneana (Maxim.) H. L. Li	1,356.82 ± 50.62	891.56 ± 109.25	44.789	0.003**
Trachelospermum jasminoides (Lindl.) Lem.	1,385.77 ± 47.51	983.64 ± 16.74	191.173	0.000**
Sedum lineare Thunb.	1,286.48 ± 41.67	2,066.17 ± 140.24	85.206	0.001**
Mentha canadensis L.	1,234.31 ± 92.36	1,274.18 ± 85.96	0.300	0.613
Hypericum patulum Thunb.	1,202.76 ± 3.01	3,594.64 ± 9.13	185,707.312	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	1,102.28 ± 2.05	3,465.47 ± 2.90	1,327,062.227	0.000**
Artemisia argyi H. Lév. & Vaniot	1,308.73 ± 1.70	1,759.03 ± 3.35	43,067.599	0.000**
Houttuynia cordata Thunb.	1,433.33 ± 20.82	1,854.68 ± 2.58	1,210.421	0.000**
Ruellia simplex C. Wright	1,337.44 ± 1.87	1,471.15 ± 3.04	4,214.164	0.000**
Echinacea purpurea (L.) Moench	1,409.44 ± 0.78	1,309.77 ± 1.15	15,356.965	0.000**
Muhlenbergia capillaris Trin.	1,470.75 ± 0.62	3,687.32 ± 2.67	1,966,069.170	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

Table 5. Effect of drought stress on POD of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Drought stress		
Lonicera japonica Thunb.	11,040.00 ± 343.95	17,356.67 ± 1,946.80	30.627	0.005**
Pyracantha fortuneana (Maxim.) H. L. Li	16,320.00 ± 1,205.16	14,506.67 ± 2,259.06	1.505	0.287
Trachelospermum jasminoides (Lindl.) Lem.	12,040.00 ± 1,518.82	18,520.00 ± 491.22	49.437	0.002**
Sedum lineare Thunb.	23,013.33 ± 1,305.00	18,576.67 ± 1,100.29	20.267	0.011*
Mentha canadensis L.	18,310.00 ± 1,003.74	20,586.67 ± 2,257.04	2.548	0.186
Hypericum patulum Thunb.	27,553.33 ± 51.32	17,861.67 ± 11.59	101,813.275	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	26,179.33 ± 2.08	19,039.33 ± 5.03	5,155,240.449	0.000**
Artemisia argyi H. Lév. & Vaniot	19,869.33 ± 5.03	19,591.00 ± 4.58	5,016.007	0.000**
Houttuynia cordata Thunb.	22,129.67 ± 9.50	19,451.67 ± 11.59	95,764.326	0.000**
Ruellia simplex C. Wright	30,010.67 ± 3.06	20,901.00 ± 1.73	20,185,790.297	0.000**
Echinacea purpurea (L.) Moench	20,610.33 ± 3.51	22,161.00 ± 4.58	216,411.040	0.000**
Muhlenbergia capillaris Trin.	19,930.33 ± 3.51	23,060.33 ± 6.51	537,634.756	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

evaluate plant drought resistance and analyze drought resistance mechanisms has great limitations. Under drought stress, each index of 12 common garden plants in Xinyang, Henan, China exhibited distinct responses to such stress. Therefore, it was more scientific and reasonable to evaluate the comprehensive drought resistance by using the average value of the correlation function obtained by combining content changes with drought resistance-related indicators. The results of this study showed that the drought tolerance of the 12 common garden plants in Xinyang was ranked from the highest to the lowest as *Muhlenbergia capillaris* Trin. > *Hypericum patulum* Thunb. > *Mentha canadensis* L. > *Artemisia argyi* H. Lév. & Vaniot > *Ruellia simplex* C. Wright > *Euonymus fortunei* (Turcz.) Hand.-Mazz. > *Houttuynia cordata* Thunb. > *Sedum lineare* Thunb. > *Trachelospermum jasminoides* (Lindl.) Lem. > *Echinacea purpurea* (L.) Moench > *Lonicera japonica* Thunb. > *Pyracantha fortuneana* (Maxim.) H. L. Li (Table 6).

Effects of flooding stress on physiological indicators of 12 plant species

(1) Soluble sugar (SS)

Table 6. Affiliation function values of physiological indicators of drought tolerance in 12 plant species.

Species	SS	SP	MDA	SOD	POD	Average of affiliation function values	Ranking
Lonicera japonica Thunb.	0.55	0.10	0.45	0.11	0.48	0.34	11
Pyracantha fortuneana (Maxim.) H. L. Li	0.26	0.12	0.84	0.03	0.22	0.30	12
Trachelospermum jasminoides (Lindl.) Lem.	0.69	0.40	0.06	0.07	0.58	0.36	9
Sedum lineare Thunb.	0.06	0.02	0.84	0.44	0.59	0.39	8
Mentha canadensis L.	0.74	0.10	0.92	0.17	0.77	0.54	3
Hypericum patulum Thunb.	1.00	0.02	0.28	0.97	0.52	0.56	2
Euonymus fortunei (Turcz.) Hand.-Mazz.	0.33	0.04	0.15	0.92	0.63	0.41	6
Artemisia argyi H. Lév. & Vaniot	0.79	0.00	0.52	0.33	0.68	0.47	4
Houttuynia cordata Thunb.	0.30	0.13	0.50	0.37	0.67	0.40	7
Ruellia simplex C. Wright	0.03	0.08	0.94	0.23	0.80	0.42	5
Echinacea purpurea (L.) Moench	0.25	0.05	0.31	0.18	0.92	0.34	10
Muhlenbergia capillaris Trin.	0.01	0.99	1.00	1.00	1.00	0.80	1

Table 7. Effect of flooding stress on SS of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Flooding stress		
Lonicera japonica Thunb.	13.55 ± 1.08	24.83 ± 4.67	16.614	0.015*
Pyracantha fortuneana (Maxim.) H. L. Li	10.91 ± 1.05	10.25 ± 1.88	0.285	0.622
Trachelospermum jasminoides (Lindl.) Lem.	19.36 ± 0.72	23.96 ± 4.23	3.448	0.137
Sedum lineare Thunb.	11.03 ± 0.45	7.57 ± 2.74	4.668	0.097
Mentha canadensis L.	62.09 ± 4.20	27.15 ± 0.78	201.115	0.000**
Hypericum patulum Thunb.	10.17 ± 0.98	23.68 ± 2.33	85.762	0.001**
Euonymus fortunei (Turcz.) Hand.-Mazz.	20.28 ± 1.48	18.50 ± 1.62	1.982	0.232
Artemisia argyi H. Lév. & Vaniot	12.72 ± 1.40	13.49 ± 2.21	0.259	0.638
Houttuynia cordata Thunb.	53.69 ± 3.21	7.12 ± 1.46	521.958	0.000**
Ruellia simplex C.Wright	5.57 ± 0.13	34.51 ± 2.06	589.046	0.000**
Echinacea purpurea (L.) Moench	21.27 ± 1.07	6.97 ± 0.97	295.134	0.000**
Muhlenbergia capillaris Trin.	3.84 ± 0.19	10.53 ± 0.69	264.773	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

The SS of the 12 plant species changed after undergoing 30 days of water flooding stress compared to that of control group. The results showed that there were highly significant differences in SS between the control group and *Mentha canadensis* L., *Hypericum patulum* Thunb., *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, *Muhlenbergia capillaris* Trin ($P < 0.01$). Further, there was a significant difference between the control group and *Lonicera japonica* Thunb. ($P < 0.05$), while not significant differences were observed between the control group and *Pyracantha fortuneana* (Maxim.) H. L. Li, *Trachelospermum jasminoides* (Lindl.) Lem., *Sedum lineare* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot (Table 7).

(2) Soluble protein (SP)

The SP of all 12 plants changed compared to that of control group after 30 days of flooding stress. Specifically, the highly significant differences in SP were found in *Trachelospermum jasminoides* (Lindl.) Lem., *Mentha canadensis* L., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.)

Table 8. Effect of flooding stress on SP of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Flooding stress		
Lonicera japonica Thunb.	523.63 ± 126.62	212.30 ± 36.00	16.780	0.015*
Pyracantha fortuneana (Maxim.) H. L. Li	204.30 ± 29.46	64.30 ± 59.81	13.228	0.022*
Trachelospermum jasminoides (Lindl.) Lem.	267.63 ± 31.09	119.30 ± 32.91	32.210	0.005**
Sedum lineare Thunb.	78.97 ± 5.51	66.63 ± 21.08	0.961	0.382
Mentha canadensis L.	348.97 ± 48.76	89.30 ± 22.61	70.034	0.001**
Hypericum patulum Thunb.	186.07 ± 6.45	21.44 ± 0.65	1,932.854	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	107.77 ± 6.22	7.25 ± 1.11	759.979	0.000**
Artemisia argyi H.Lév. & Vaniot	171.23 ± 1.22	83.98 ± 1.45	6,326.318	0.000**
Houttuynia cordata Thunb.	97.20 ± 6.22	102.42 ± 2.36	1.849	0.245
Ruellia simplex C. Wright	75.87 ± 3.71	36.64 ± 1.63	281.272	0.000**
Echinacea purpurea (L.) Moench	101.27 ± 2.45	70.56 ± 2.21	260.242	0.000**
Muhlenbergia capillaris Trin.	112.93 ± 2.41	29.91 ± 1.35	2,706.932	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

Table 9. Effect of flooding stress on MDA of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Flooding stress		
Lonicera japonica Thunb.	257.98 ± 40.01	558.19 ± 10.32	158.389	0.000**
Pyracantha fortuneana (Maxim.) H. L. Li	10.24 ± 2.98	104.86 ± 50.33	10.568	0.031*
Trachelospermum jasminoides (Lindl.) Lem.	218.41 ± 64.12	139.27 ± 14.21	4.356	0.105
Sedum lineare Thunb.	9.38 ± 2.98	24.36 ± 4.19	25.444	0.007**
Mentha canadensis L.	151.31 ± 55.49	73.03 ± 11.25	5.735	0.075
Hypericum patulum Thunb.	826.91 ± 17.18	191.55 ± 2.00	4,046.109	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	271.58 ± 1.16	234.56 ± 3.95	242.831	0.000**
Artemisia argyi H. Lév. & Vaniot	152.75 ± 13.86	257.77 ± 1.19	171.089	0.000**
Houttuynia cordata Thunb.	104.07 ± 1.90	31.67 ± 0.39	4,175.332	0.000**
Ruellia simplex C. Wright	36.64 ± 2.95	78.49 ± 0.64	578.856	0.000**
Echinacea purpurea (L.) Moench	177.57 ± 2.83	199.35 ± 0.41	173.380	0.000**
Muhlenbergia capillaris Trin.	103.67 ± 2.16	104.56 ± 0.62	0.467	0.532

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot, *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, *Muhlenbergia capillaris* Trin. ($P < 0.01$)., and significant differences were found in *Lonicera japonica* Thunb. and *Pyracantha fortuneana* (Maxim.) H. L. Li ($P < 0.05$). There were no significant differences observed in *Sedum lineare* Thunb. and *Houttuynia cordata* Thunb (Table 8).

(3) Malondialdehyde (MDA)

The MDA of all 12 plants changed after 30 days of flooding stress compared to that of control group. The MDAs of *Lonicera japonica* Thunb., *Sedum lineare* Thunb., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, and *Echinacea purpurea* (L.) Moench demonstrated highly significant differences compared to the control group ($P < 0.01$), while the MDA of *Pyracantha fortuneana* (Maxim.) H. L. Li showed significant difference compared to the control group ($P < 0.05$). No significant differences were observed in *Trachelospermum jasminoides* (Lindl.) Lem., *Mentha canadensis* L., and

Table 10. Effect of flooding stress on SOD of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Flooding stress		
Lonicera japonica Thunb.	1,410.24 ± 39.18	2,131.87 ± 101.27	132.492	0.000**
Pyracantha fortuneana (Maxim.) H. L. Li	1,356.82 ± 50.62	2,365.25 ± 14.90	1,095.786	0.000**
Trachelospermum jasminoides (Lindl.) Lem.	1,385.77 ± 47.51	1,460.47 ± 17.73	6.509	0.063
Sedum lineare Thunb.	1,286.48 ± 41.67	1,640.86 ± 185.05	10.471	0.032*
Mentha canadensis L.	1,234.31 ± 92.36	1,579.17 ± 84.09	22.870	0.009**
Hypericum patulum Thunb.	1,202.76 ± 3.01	1,454.68 ± 4.00	7,611.155	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	1,102.28 ± 2.05	1,198.39 ± 8.55	358.173	0.000**
Artemisia argyi H. Lév. & Vaniot	1,308.73 ± 1.70	1,649.54 ± 30.19	381.178	0.000**
Houttuynia cordata Thunb.	1,433.33 ± 20.82	1,427.02 ± 7.82	0.242	0.648
Ruellia simplex C. Wright	1,337.44 ± 1.87	1,253.16 ± 1.62	3,483.051	0.000**
Echinacea purpurea (L.) Moench	1,409.44 ± 0.78	2,176.99 ± 2.80	209,619.804	0.000**
Muhlenbergia capillaris Trin.	1,470.75 ± 0.62	1,503.34 ± 3.85	209.597	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

Table 11. Effect of flooding stress on POD of 12 plant species.

Species	Value (mean ± SD)		*F*	*P*
	Control	Flooding stress		
Lonicera japonica Thunb.	11,040.00 ± 343.95	10,776.67 ± 1,504.01	0.087	0.782
Pyracantha fortuneana (Maxim.) H. L. Li	16,320.00 ± 1,205.16	10,316.67 ± 943.84	46.141	0.002**
Trachelospermum jasminoides (Lindl.) Lem.	12,040.00 ± 1,518.82	13,446.67 ± 1,382.37	1.407	0.301
Sedum lineare Thunb.	23,013.33 ± 1,305.00	13,323.33 ± 2,457.85	36.375	0.004**
Mentha canadensis L.	18,310.00 ± 1,003.74	18,570.00 ± 5,804.58	0.006	0.943
Hypericum patulum Thunb.	27,553.33 ± 51.32	12,533.00 ± 7.00	252,329.281	0.000**
Euonymus fortunei (Turcz.) Hand.-Mazz.	26,179.33 ± 2.08	18,431.67 ± 6.66	3,700,253.760	0.000**
Artemisia argyi H. Lév. & Vaniot	19,869.33 ± 5.03	14,139.33 ± 3.06	2,841,308.654	0.000**
Houttuynia cordata Thunb.	22,129.67 ± 9.50	11,071.00 ± 5.57	3,023,755.429	0.000**
Ruellia simplex C. Wright	30,010.67 ± 3.06	14,840.33 ± 3.51	31,865,401.862	0.000**
Echinacea purpurea (L.) Moench	20,610.33 ± 3.51	16,940.33 ± 2.52	2,164,644.643	0.000**
Muhlenbergia capillaris Trin.	19,930.33 ± 3.51	14,920.00 ± 1.00	5,648,274.025	0.000**

Note: $^{*}P < 0.05$. $^{**}P < 0.01$.

Muhlenbergia capillaris Trin. (Table 9).

(4) Superoxide dismutase (SOD)

The SOD changes of all 12 plants compared to the control group under 30 days of flooding stress showed that *Lonicera japonica* Thunb., *Pyracantha fortuneana* (Maxim.) H. L. Li, *Mentha canadensis* L., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. & Vaniot, *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, *Muhlenbergia capillaris* Trin. demonstrated highly significant difference ($P < 0.01$), while *Sedum lineare* Thunb. demonstrated significant difference ($P < 0.05$). There were no significant differences observed in *Trachelospermum jasminoides* (Lindl.) Lem. and *Houttuynia cordata* Thunb. (Table 10).

(5) Peroxidase (POD)

The POD changes of all 12 plants compared to the control group under 30 days of flooding stress demonstrated that *Pyracantha fortuneana* (Maxim.) H. L. Li, *Sedum lineare* Thunb., *Hypericum patulum* Thunb., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Artemisia argyi* H. Lév. &

Table 12. Affiliation function values of physiological indicators of flooding tolerance in 12 plant species.

Species	SS	SP	MDA	SOD	POD	Average of affiliation function values	Ranking
Lonicera japonica Thunb.	0.81	0.85	0.02	0.80	0.13	0.52	3
Pyracantha fortuneana (Maxim.) H. L. Li	0.23	0.24	0.85	0.99	0.10	0.48	6
Trachelospermum jasminoides (Lindl.) Lem.	0.77	0.47	0.78	0.23	0.33	0.52	4
Sedum lineare Thunb.	0.12	0.25	0.99	0.38	0.32	0.41	7
Mentha canadensis L.	0.90	0.34	0.91	0.33	0.72	0.64	1
Hypericum patulum Thunb.	0.76	0.06	0.69	0.22	0.26	0.40	9
Euonymus fortunei (Turcz.) Hand.-Mazz.	0.55	0.00	0.61	0.01	0.71	0.38	11
Artemisia argyi H. Lév. & Vaniot	0.35	0.32	0.57	0.39	0.39	0.40	8
Houttuynia cordata Thunb.	0.10	0.40	0.98	0.20	0.15	0.37	12
Ruellia simplex C. Wright	1.20	0.13	0.90	0.05	0.44	0.54	2
Echinacea purpurea (L.) Moench	0.09	0.27	0.67	0.83	0.60	0.49	5
Muhlenbergia capillaris Trin.	0.24	0.10	0.85	0.27	0.44	0.38	10

Vaniot, *Houttuynia cordata* Thunb., *Ruellia simplex* C. Wright, *Echinacea purpurea* (L.) Moench, *Muhlenbergia capillaris* Trin. showed highly significant differences ($P < 0.01$), while *Lonicera japonica* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Mentha canadensis* L. showed no significant differences (Table 11).

Comprehensive evaluation of flooding tolerance of 12 plant species

Under the flooding stress, each index of 12 common garden plants in Xinyang responded differently to the flooding stress. Since a single index could not fully reflect the strength of its comprehensive flooding tolerance, it was more scientific and reasonable to utilize the content change and flooding-tolerance-related indexes, and the average value of the affiliation function obtained by the synthesis to evaluate the strength of its comprehensive flooding tolerance. The flooding tolerance of 12 common garden plants in Xinyang was ranked as *Mentha canadensis* L. > *Ruellia simplex* C. Wright > *Lonicera japonica* Thunb. > *Trachelospermum jasminoides* (Lindl.) Lem. > *Echinacea purpurea* (L.) Moench > *Pyracantha fortuneana* (Maxim.) H. L. Li > *Sedum lineare* Thunb. > *Artemisia argyi* H. Lév. & Vaniot > *Hypericum patulum* Thunb. > *Muhlenbergia capillaris* Trin. > *Euonymus fortunei* (Turcz.) Hand.-Mazz. > *Houttuynia cordata* Thunb. (Table 12).

Composite evaluation of 12 plant species against drought and flooding stresses

In the sponge city environment, plants frequently encounter the composite cross impacts of multiple short-term harsh conditions such as drought and flooding. The total scores of the affiliation function of drought stress and flooding stress in this study were compiled and averaged to produce a composite evaluation of plant responses under these multiple stressors. Subsequently, 12 selected plants were ranked in order of stress tolerance to evaluate the strength of their composite stress tolerance. The composite evaluation of 12 common garden plants in Xinyang under drought and flooding composite stress was ranked from the highest to the lowest as *Mentha canadensis* L. > *Muhlenbergia capillaris* Trin. > *Hypericum patulum* Thunb. > *Ruellia simplex* C. Wright > *Trachelospermum jasminoides* (Lindl.) Lem. > *Artemisia argyi* H. Lév. & Vaniot > *Lonicera japonica* Thunb. > *Echinacea purpurea* (L.) Moench > *Sedum lineare* Thunb. > *Euonymus fortunei* (Turcz.) Hand.-Mazz. > *Pyracantha fortuneana* (Maxim.) H. L. Li > *Houttuynia cordata* Thunb. (Table 13).

Table 13. Composite evaluation of 12 plant species under drought and flooding stresses.

Species	Affiliation function values in drought stress	Affiliation function values in flooding stress	Average of affiliation function values	Ranking
Lonicera japonica Thunb.	0.335	0.521	0.428	7
Pyracantha fortuneana (Maxim.) H. L. Li	0.295	0.480	0.388	11
Trachelospermum jasminoides (Lindl.) Lem.	0.361	0.517	0.439	5
Sedum lineare Thunb.	0.391	0.413	0.402	9
Mentha canadensis L.	0.539	0.640	0.590	1
Hypericum patulum Thunb.	0.559	0.400	0.480	3
Euonymus fortunei (Turcz.) Hand.-Mazz.	0.414	0.377	0.396	10
Artemisia argyi H. Lév. & Vaniot	0.466	0.404	0.435	6
Houttuynia cordata Thunb.	0.395	0.367	0.381	12
Ruellia simplex C. Wright	0.417	0.542	0.479	4
Echinacea purpurea (L.) Moench	0.342	0.493	0.417	8
Muhlenbergia capillaris Trin.	0.799	0.378	0.589	2

Discussion

Drought represents a significant environmental factor that adversely impacts the growth and development of plants. In response to drought conditions, plants undergo a series of adjustments and changes in growth and physiology to adapt to the environment [14, 15]. Flooding is one of the weather extremes that plants must contend with. Drought stress and flooding stress have a significant impact on the reactive oxygen metabolism system of plants, which affects the balance between the production and removal of reactive oxygen free radicals. This disruption can lead to membrane lipid peroxidation. MDA is the final decomposition product of cytoplasmic peroxidation and serves as an indicator of the extent of injury and tolerance of the membrane system, as well as toxic effects on cells [16]. Antioxidant enzyme system is a membrane protection system of plant cells against reactive oxygen species, effectively scavenging oxygen radicals and hydrogen peroxide, *etc*., thus minimizing or preventing the formation of hydroxyl radicals [17]. SOD is the first line of defense for the scavenging of reactive oxygen species in plants and is at the core of the antioxidant enzyme system, primarily facilitating the conversion of superoxide radicals into hydrogen peroxide [18]. POD, as the second line of defense for scavenging reactive oxygen species in plants, mainly scavenges hydrogen peroxide diverted from SOD and decomposes it into water and oxygen, thus minimizing the formation of hydroxyl radicals [18]. In addition, drought and flooding stress also have a great impact on the osmoregulation mechanism of plants. Under drought stress, plants actively accumulate cellular solutes to reduce the osmotic potential, improve cellular water retention, and maintain cellular expansion pressure, thus ensuring plant physiological processes [19]. SS and SP are the essential substances for osmoregulation in plant leaves, and plants resist extreme drought environments by elevating the levels of both. Maintaining a high SS content in flooded environments may facilitate a rapid resumption of growth process [20]. SP in plants can provide binding substrates for bound water to increase the bound water content of plants, improve the water retention of plant tissues, and reduce the damage of water stress on plants [11, 21].

In this study, at the end of the drought stress experiment, the change values of MDA, SOD, POD, SS, and SP of the 12 plants varied greatly, indicating that the drought tolerance among the 12 plants differed, and the drought tolerance of the 12 plants could be ranked by scoring the above five indexes through the affiliation function. Among the 12 selected plants, the score value of *Muhlenbergia capillaris* Trin. was 0.80, which was much higher than that of the second ranked *Hypericum patulum* Thunb. with a score of 0.56. Eight plants whose affiliation function scores ranked within the lower range of 0.42 - 0.30 demonstrated not much difference in the scores of the sorted neighboring plants. From a comprehensive point of view, the drought resistance of *Muhlenbergia capillaris* Trin. was the strongest, which could be classified as a strong-drought-tolerant plant followed by *Hypericum patulum* Thunb., *Mentha canadensis* L., and *Artemisia argyi* H. Lév. & Vaniot whose affiliation function scores were 0.56, 0.54, 0.47, respectively, and could be classified as a moderate-drought-tolerant plant. *Ruellia simplex* C. Wright, *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Houttuynia cordata* Thunb., *Sedum lineare* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Echinacea purpurea* (L.) Moench, *Lonicera japonica* Thunb., and *Pyracantha fortuneana* (Maxim.) H. L. Li belonged to the not-drought-tolerant plants. According to the results of this study, on the selection of plant landscaping in the sponge city construction, priority could be given to choose *Muhlenbergia capillaris* Trin. followed by *Hypericum patulum* Thunb., *Mentha canadensis* L., and *Artemisia argyi* H. Lév. & Vaniot. If it was necessary to choose *Ruellia simplex* C. Wright, *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Houttuynia cordata* Thunb., *Sedum lineare* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Echinacea purpurea* (L.) Moench, *Lonicera japonica* Thunb., and *Pyracantha fortuneana* (Maxim.) H. L. Li for landscaping, it was essential to ensure proper compatibility during the initial planning phase, which included increasing surface cover appropriately and minimizing water evaporation to mitigate the risk of the plants encountering drought conditions. Furthermore, during subsequent maintenance, it was advisable to adjust irrigation practices in accordance with climatic conditions to ensure timely replenishment of water resources.

At the end of the flooding stress experiment, the differences in the change values of MDA, SOD, POD, SS, and SP of the 12 plants varied greatly, indicating that the flooding tolerance among the 12 plants differed. The scoring of the above five indicators through the affiliation function showed the high or low level of flooding tolerance of the 12 plant species. The affiliation function score of *Mentha canadensis* L. was 0.64, which could be classified as a strong-flooding-tolerant plant. The affiliation function scores of *Ruellia simplex* C. Wright, *Lonicera japonica* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Echinacea purpurea* (L.) Moench, *Pyracantha fortuneana* (Maxim.) H. L. Li were 0.54, 0.52, 0.52, 0.49, 0.48, respectively, with little difference in the scores, which could be classified as moderate-flooding-tolerant plants. *Sedum lineare* Thunb., *Artemisia argyi* H. Lév. & Vaniot, *Hypericum patulum* Thunb., *Muhlenbergia capillaris* Trin., *Euonymus fortunei* (Turcz.) Hand.-Mazz., and *Houttuynia cordata* Thunb. showed low affiliation function scores, ranging from 0.41 to 0.37, and the scores were similar to each other, which could be classified as no-flooding-tolerant plants.

According to the above classification, in the sponge city construction, if the planning area is likely to experience prolonged flooding, particularly where the soil has low permeability or in low-lying regions that are prone to inundation, in terms of plant landscaping, priority should be given to *Mentha canadensis* L., a strong-flood-tolerant plant, followed by moderate-flood-tolerant *Ruellia simplex* C. Wright, *Lonicera japonica* Thunb., *Trachelospermum jasminoides* (Lindl.) Lem., *Echinacea purpurea* (L.) Moench, and *Pyracantha fortuneana* (Maxim.) H. L. Li, while *Sedum lineare* Thunb., *Artemisia argyi* H. Lév. & Vaniot, *Hypericum patulum* Thunb., *Muhlenbergia capillaris* Trin., *Euonymus fortunei* (Turcz.) Hand.-Mazz., and *Houttuynia cordata* Thunb. should avoid to be planted in low-lying areas that are susceptible to long-term flooding and should be planted in areas of good drainage such as slopes, according to the needs of landscaping in order to increase the survival rate of the plant.

Through a comprehensive evaluation of drought and flooding stress tolerance of 12 plants, the results showed that four plants including *Mentha canadensis* L., *Muhlenbergia capillaris* Trin., *Hypericum patulum* Thunb., and *Ruellia simplex* C. Wright had the strongest composite tolerance to both drought and flooding stress. These species were deemed particularly suitable for cultivation in sponge cities, specifically within the buffer zones of sunken green belts and rain gardens, where they were likely to experience prolonged periods of both drought and flooding during the rainy season. *Artemisia argyi* H. Lév. & Vaniot, *Euonymus fortunei* (Turcz.) Hand.-Mazz., and *Houttuynia cordata* Thunb. were the strong-drought-resistant and weak-flood-resistant plants, which were more appropriately planted in sponge cities that primarily utilized infiltration functions as their main sponge facilities such as grass ditches designed for rainwater transmission, as well as along the edges of sunken green belts and rain gardens. Meanwhile, the planting soil should be constructed using a more permeable medium with a recommended emptying time of 12 h. *Trachelospermum jasminoides* (Lindl.) Lem., *Lonicera japonica* Thunb., *Echinacea purpurea* (L.) Moench, *Sedum lineare* Thunb., and *Pyracantha fortuneana* (Maxim.) H. L. Li were strong-tolerant-flooding and weak-tolerant-drought plants, which were best suited for installation in sponge facilities that primarily served water storage functions. Such facilities included the storage areas of sunken green belt and rain gardens, as well as other locations that were prone to flooding for extended durations with a recommended drainage time of 48 hours.

Acknowledgements

This research was funded by the China Institute of Urban Planning and Design (Beijing) Co., Ltd. Lateral Scientific Research Projects “Physiological responses and composite evaluation of common garden plants in Xinyang to multiple stresses” (Grant No. 20240305).

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