Selection and Evaluation of Suitable Tree Species in Drought and High-dust Coal Base in Northwest China

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**Selection and Evaluation of Suitable Tree Species in Drought and
High-Dust Coal Base in Northwest China**

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Abstract

To select drought-resistant and dust-tolerant tree species suitable for being planted in a drought-ridden and high-dust coal base in northwest China, we used nine tree species to determine the growth status, biomass, harm index, and photosynthetic characteristics under drought and highly dusty stress conditions. The results showed that in the drought resistance index system, their cumulative contribution rate reached 98.1%, and the drought resistance order was *Ammopiptanthus mongolicus* > *Hedysarum scoparium* > *Sabina vulgaris* > *Caragana korshinskii* > *Ulmus pumila* > *Amorpha fruticosa* > *Caryopteris mongholica* > *Tamarix chinensis* > *Elaeagnus angustifolia*. In the dust resistance index system, the cumulative contribution rate reached 95.2%. The dust resistance order was *Caragana korshinskii* > *Amorpha fruticosa* > *Sabina vulgaris* > *Hedysarum scoparium* > *Tamarix chinensis* > *Ammopiptanthus mongolicus* > *Ulmus pumila* > *Caryopteris mongholica* > *Elaeagnus angustifolia*. In the drought and dust resistance comprehensive index system, 14 indices (shoot length, stomatal conductance, and POD) had larger weights and the cumulative contribution of comprehensive indices reached 100%. The drought and dust resistance order of the test tree species was *Caragana korshinskii* > *Ulmus pumila* > *Amorpha fruticosa* > *Sabina vulgaris* > *Caryopteris mongholica* > *Ammopiptanthus mongolicus* > *Hedysarum scoparium* > *Tamarix chinensis* > *Elaeagnus angustifolia*. These results provided a reference for the selection of suitable greening tree species in accordance with local conditions in drought-mining areas.

Keywords: coal base; afforestation tree species; drought resistance; dust resistance; evaluation index system

1. Introduction

Drought is the main factor limiting plant growth in northwest China (Li et al., 2010; Na et al., 2018; Zhao et al., 2018). The precipitation in northwest China is always low, which causes dry air and soil dehydration, resulting in a water deficit in plants and affecting normal growth and development of plants (Wang et al., 2015). About one-third of China's land is in arid regions, and drought and lack of water resources are the most important factors restricting economic and social development as well as the construction of an ecological environment in these regions (Ji et al., 2006; Li et al., 2010). Dry climate, low annual precipitation, and severe evaporation severely restrict the growth and development of plants (Li et al., 2010; Sun et al., 2003; Wang et al., 2015), and thus, the research and application of drought-resistant plants is particularly important. Drought-resistant plants are plants that can tolerate long-term drought conditions and grow normally (Chang et al., 2018; Li et al., 2010;). The drought resistance mechanisms of drought-resistant plants usually are studied from the morphological structure and physiological and biochemical indices of plants (Hu et al., 1998; Liu et al., 1994; Shan et al., 1999).

There are many studies on the dust resistance of plants (Nurmamat et al., 2017; Shah et al., 2018; Wang et al., 2015; Zhang et al., 2015). Most of these studies have focused on the dust retention of urban and park greening tree species (Joshi et al., 2007;

1 Li et al., 2016; Lin et al., 2014; Tang 2017; Wang et al.,2015) and some studies have
2 focused on urban air pollution control, including the function and mechanism of urban
3 greening trees to purify air and the dust retention function of urban greening tree species
4 (Beckett et al., 1998; Prajapati and Tripathi 2008; Wang et al., 2015; Zheng 2013; Zhang
5 et al., 2015(a); Zhang et al., 2015(b)). Highly concentrated airborne particulate matter,
6 sulfur dioxide (SO₂), and nitric oxide (NO_x) seriously harm human health, causing
7 respiratory symptoms and increasing the risk of obstructing the lungs (Burtraw et al.,
8 2003; Fan 2014). Additionally, the strong scattering effect of fine particles decreases
9 air visibility and induces hazy weather (Shang et al., 2011; Wu 2012). Therefore, in
10 light of new problems introduced by air pollution, research on the dust resistance of
11 plants has been continuously expanded and deepened in recent years (Nurmamat et al.,
12 2017; Salmond et al., 2013; Tang 2017; Zhang et al., 2017; Zheng 2013). These studies
13 have enriched the focus of plant selection from different perspectives. The dust
14 pollution in mining areas is much higher than that in cities, but studies have rarely
15 focused on the dust resistance of tree species selected in mining areas.

16 The selection of drought-resistant plants has always been an important subject for
17 vegetation construction in northwest China (Li et al., 2010; Na et al., 2018; Wang et al.,
18 2015; Zhao et al., 2018). Coal bases in arid areas require drought-resistant tree species
19 because of the lack of water, and the growth of trees in such bases has been harmed
20 seriously because of the dust and other pollution caused by coal development. Tree
21 species need not only withstand drought and water shortage but also bear the hazards
22 of particulate matter, such as severe dust. These two indices are indispensable, in which

dust resistance includes dust retention and antidusting (Lin et al., 2014; Losfeld et al., 2014; Schleicher et al., 2011; Wang 2011; Zhang 2016). Therefore, afforestation tree species need to have both drought resistance and dust resistance. Few studies have been conducted on the election of tree species in arid coal mine areas in northwest China, especially in high-dust sites in coal mine areas. Therefore, this study observed multiple growth and physiological indices to analyze the drought resistance and dust resistance.

2. Materials and Methodology

2.1. Overview of the test area

We conducted a dust resistance test at the Yangchangwan Coal Mine of Shenhua Ningxia Coal Industry Group. We tested drought resistance at a nearby test farm where the east longitude is 106°23'75.87"—106°59'67.57", the northern latitude is 38°00'42.79"—38°23'01.88", and the altitude is 1,117–1,232 m. The climate is semi-arid desert continental monsoon climate, and diurnal temperature variation is large. In 2018, average annual temperature was 8.8°C, average annual rainfall was 206.2 mm, average frost-free period was 167 d, and average annual evaporation was 1,470.1 mm.

2.2. Test materials and methods

This study adopted the seedling of *Caragana korshinskii* Kom., *Tamarix chinensis* Lour., *Amorpha fruticosa* Linn., *Hedysarum scoparium* Fisch. etMey., *Ammopiptanthus mongolicus*, *Caryopteris mongholica* Bunge, *Sabina vulgaris* Ant., *Ulmus pumila* L., and *Elaeagnus angustifolia* Linn. Principal component analysis (PCA) was used to calculate the weight of each index and to establish a tree drought resistance evaluation index system (Xie and Hu 2016; Guo and Wang 2018).

Among the early potted seedlings, we selected one-year robust potted seedlings with basically consistent growth vigor. The size of the test pot was upper diameter * lower diameter * height = 580 mm * 450 mm * 520 mm. The potting soil was simulated earthing soil of waste rock field from the Lingwu Yangchangwan Coal Mine (its physicochemical properties are shown in Table 1). In April 2018, we planted the selected tree species in the coal-mining areas for the drought resistance and dust retention test. The detailed planting methods are shown in Fig. 1

In the drought resistance test, we conducted progressive water stress treatment using the pot-water control method and adopted single-factor design. We set up a natural drought treatment group and control group. All plants were fully irrigated three days before the test to ensure that the soil in each pot was saturated. We stopped watering the plants in the drought treatment group after the test, and watered these plants again 30 days after drought stress. The plants in the control groups were watered every seven days. For the dust resistance test, we selected the dust-contaminated coal-mining areas (waste rock field) for the potted species. The dust retention per unit area was 1.08–2.76 g/m²/week, and the plants were watered every seven days. After rainfall (>15 mm), we measured the relevant indices in dust resistance and drought resistance tests every seven days. We replicated the test with 10 pots of each tree species.

2.3. Measurement indices

2.3.1 Growth indices and biomass

At the beginning and end of the drought resistance and dust retention test, we measured growth indices (plant height, ground diameter, shoot length, and crown

breadth) to calculate the net growth. We dug out three whole plants out to measure biomass of the stems, leaves, and roots, and we calculated the water content of leaves ($= (\text{leaf fresh mass} - \text{leaf dry mass}) / \text{leaf fresh mass}$), plant water content, leaf biomass ratio ($= \text{leaf dry mass} / \text{plant dry mass}$), root biomass ratio, stem biomass ratio ($= \text{stem dry mass} / \text{plant dry mass}$), root shoot ratio ($\text{root dry mass} / \text{upper ground dry mass}$), and the length of the main root system.

2.3.2 Main indices of drought resistance and dust resistance

We measured 28 drought-resistant physiological indices, including superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and other enzyme activities; photosynthetic characteristic parameters; water consumption; leaf water saturation deficit; and 20 dust resistance indices, including dust retention per unit leaf area, dust retention per unit leaf weight, stomatal conductance, main root system length, transpiration rate, photosynthetic rate, harm index, and water use efficiency.

2.3.3 Dust retention per unit leaf weight and area and specific leaf weight

We randomly selected 30 leaves after rainfall (within seven days) and measured the amount of dust retention by the cleaning method. We measured leaf area with a portable leaf area meter, which were recorded as $S_1, S_2, \dots, S_{30}$ (cm^2). The washed leaves were dried and weighed to calculate the specific leaf weight, as follows:

$$\text{Dust retention per unit leaf area (g / m}^2\text{)} = \frac{M_1 - M_2}{\sum S_i (i=1,2,\dots,30)} \times 10^4$$

$$\text{Dust retention per unit fresh leaf weight (g/g)} d_f = M / W_f,$$

where d_f is the amount of dust retention per unit fresh leaf weight (g/g); W_f is the total leaf fresh weight of the sample (g); and M is the total dust retention of all leaves of the samples (g).

2.3.4 Harm index

To observe the impact of dust retention on plant morphology, we established a classification standard for leaf damage caused by dust retention (see Table 2). In the dust resistance test, we investigated and classified 10 leaves of different orientations (east, west, south, north) and parts (upper, middle, and lower) of each tree species according to the following harm degree and calculated their harm indices:

$$\text{Harm index} = \frac{\sum(\text{Harm grade leaves} * \text{Harm grade representative value})}{(\text{Total investigated leaves} * \text{Highest harm grade value})} * 100\%.$$

Table 3 shows the harmed symptoms and grades of leaves from different tree species after dust retention, and the grades of the harmed leaves from left to right are 0, 1, 2, 3, 4, and 5. *Sabina vulgaris* was less affected by dust retention and only showed harmed symptoms of grade 0 and grade 1.

2.3.5 Photosynthetic physiology

At the beginning, middle, and end periods of the test, with the TARGAS-1 portable photosynthesis analyzer (PP Systems, Amesbury, MA, USA), we randomly selected three leaves of different plants on the sunny side from 9:00 to 11:00 a.m. on sunny days to measure the photosynthetic physiology of different tree species. The indices included transpiration rate, stomatal conductance, photosynthetic rate, intercellular carbon dioxide (CO₂) concentration, and water use efficiency.

2.4 Data processing and analysis

The drought resistance coefficient and dust resistance coefficient were calculated, and then the reverse indices were converted into positive indices (Liu et al., 2014 and Liu 2009) and SPSS 21.0 was applied to process the data.

(1) Coefficients of drought and dust resistance:

Drought resistance coefficient = (measurement value of drought stress
group/measurement value of control group) * 100%. (1)

Dust resistance coefficient = (measurement value of dust retention treatment
group/ measurement value of control group) * 100%. (2)

(2) Calculation of membership function value $U(X_j)$ of each comprehensive index
(Zhang et al., 2014):

$$U(X_j) = (X_j - X_{min}) / (X_{max} - X_{min}) \quad j = 1, 2, \dots, n, \quad (3)$$

where X_j represents the j -th comprehensive index, and X_{max} and X_{min} represent the
maximum and minimum values of the j -th comprehensive index, respectively.

(3) Calculation of weights of various comprehensive indices (Dong et al., 2016;
Shi et al., 2015):

$$W_j = \frac{p_j}{\sum_{j=1}^n p_j} \quad j = 1, 2, \dots, n, \quad (4)$$

where W_j represents the importance degree of the j -th comprehensive index in all the
comprehensive indices, that is, weight; and P_j represents the contribution rate of the j -
th comprehensive index of each tree species obtained through principal component
analysis.

(4) Comprehensive drought and dust resistance of each tree species:

$$D = \sum_{j=1}^n U(X_j) \times W_j \quad j = 1, 2, \dots, n, \quad (5)$$

where the D value refers to the comprehensive evaluation value of drought resistance
or dust resistance obtained by a comprehensive index evaluation of each tree species
under drought stress or dust retention stress (Zhu et al., 2011).

3. Results and Analysis

3.1 Screening and evaluation of drought resistance indices of tree species

3.1.1 Establishment of evaluation index system for drought resistance of tree species

Table 4 shows the weight of each index and drought resistance evaluation index system. The greater the weight was, the greater the importance of the index. Among these indices, water consumption, RWC (relative water content), RWD (relative water deficit), conductivity, SOD content, and POD content had relatively large weights (>0.05), which were the main indices for our comprehensive evaluation of drought resistance of tree species.

3.1.2 Comprehensive evaluation of drought resistance of tree species

Table 5 shows the drought resistance coefficients of 28 individual indicators of nine tree species. The contribution rates of the first seven comprehensive indices were 26.9%, 18.9%, 16.4%, 12.3%, 10.9%, 7.1%, and 5.3%, and their cumulative contribution rate reached 98.1%. Thus, we transformed 28 individual indicators into new and independent comprehensive indicators C_{11} – C_{17} .

We used equations (3) and (4) to obtain the membership function values and weights of the seven comprehensive indices, and then used equation (5) to obtain the D value of the comprehensive evaluation of drought resistance. According to the D value and ranking, the order of the drought resistance of nine tree species was as follows (Table 6): *Ammopiptanthus mongolicus* (0.6750) > *Hedysarum scoparium* (0.6265) > *Sabina vulgaris* (0.62633) > *Caragana korshinskii* (0.6053) > *Ulmus pumila* (0.5952) >

1 *Amorpha fruticosa* (0.5357) > *Caryopteris mongholica* (0.5276) > *Tamarix chinensis*
2 (0.4817) > *Elaeagnus angustifolia* (0.1935). *Ammopiptanthus mongolicus* and
3 *Hedysarum scoparium* had stronger drought resistance; *Elaeagnus angustifolia* and
4 *Tamarix chinensis* had less drought resistance.

5

6 **3.2 Screening and evaluation of dust resistance indices of tree species**

7 **3.2.1 Establishment of evaluation index system for dust resistance of tree species**

8 Under a dust environment, tree species reflect their adaptability through intuitive
9 changes in morphology and structure and biomass allocation. The amount of dust
10 retention on the leaves indirectly reflects the pollution of the surrounding air, and the
11 harm indices of the leaves more intuitively reflect the harmed situation of the tree
12 species by the dust retention. Dust retention per unit leaf area, dust retention per unit
13 leaf weight, stomatal conductance, main root system length, transpiration rate,
14 photosynthetic rate, harm index, water use efficiency, and root biomass ratio had a
15 relatively high weight (>0.05) and could be used as the main indices to evaluate the
16 dust resistance of tree species (Table 7).

17 **3.2.2 Comprehensive evaluation of dust resistance of tree species**

18 The dust resistance coefficients were calculated and the results showed that the
19 contribution rates of the first six comprehensive indices were 30.5%, 18.8%, 16.1%,
20 13.4%, 9.3%, and 7.1%, and the cumulative contribution rate reached 95.2% (Table 8).
21 Thus, we transformed 20 individual indicators into new and independent
22 comprehensive indicators CI_1 – CI_6 . Table 9 shows the D value of the comprehensive
23 evaluation of dust resistance: *Caragana korshinskii* > *Amorpha fruticosa* > *Sabina*

1 *vulgaris* > *Hedysarum scoparium* > *Tamarix chinensis* > *Ammopiptanthus mongolicus* >
2 *Ulmus pumila* > *Caryopteris mongholica* > *Elaeagnus angustifolia*. *Caragana*
3 *korshinskii* and *Amorpha fruticosa* had stronger dust resistance and the D value reached
4 0.5782 and 0.5139, respectively. The less dust-resistant species were *Caryopteris*
5 *mongholica* and *Elaeagnus angustifolia*.

6

7 **3.3 Comprehensive evaluation of drought and dust resistance**

8 The drought resistance and dust resistance indices included seven primary indices
9 and 48 secondary indices. Among the indices, shoot length (dust retention), stomatal
10 conductance (dust retention), crown breadth (dust retention), POD content (drought
11 resistance), stem biomass ratio (dust retention), and transpiration rate (drought
12 resistance), SOD content (drought resistance), dust retention per unit weight (dust
13 retention), photosynthetic rate (dust retention), water consumption (drought resistance),
14 malondialdehyde (MDA) content (drought resistance), intercellular CO₂ concentration
15 (drought resistance), CAT content (drought resistance), and survival rate (drought
16 resistance) had a relatively large weight (> 0.03). We used these indices as the main
17 indices to evaluate drought resistance and dust resistance of tree species.

18 The contribution rates of the first eight comprehensive indices were 22.402%,
19 18.562%, 14.483%, 13.197%, 10.318%, 10.095%, 6.726%, and 4.217%, and their
20 cumulative contribution rate reached 100%. Thus, we transformed 48 individual
21 indicators into new and independent comprehensive indicators CI_1 – CI_9 . The D value of
22 the comprehensive evaluation of drought and dust resistance of each tree species was

1 *Caragana korshinskii* > *Ulmus pumila* > *Amorpha fruticosa* > *Sabina vulgaris* >
2 *Caryopteris mongholica* > *Ammopiptanthus mongolicus* > *Hedysarum scoparium* >
3 *Tamarix chinensis* > *Elaeagnus angustifolia*. *Caragana korshinskii* and *Ulmus pumila*
4 had stronger drought and dust resistance (Table 10).

5

6 **4. Discussion**

7 The selection of afforestation tree species has been an important subject in forestry
8 research. It generally is believed that because of the drought and water shortage in
9 northwest China, tree species with good drought resistance are the key to overcoming
10 tree growth and survival under water shortage conditions. This view is not incorrect,
11 but not all problems can be solved with trees that have drought resistance or with
12 irrigation, including air pollution resistance. In some cases, trees grow normally without
13 serious pollution but cannot grow normally and even may die in certain cases of air
14 pollution even if the irrigation water is sufficient. In such cases, the anti-pollution
15 capacity of a tree species needs to be given priority.

16 This research introduced multiple variables while also incorporating the complex
17 factors into several principal components, which simplified the problem and obtained
18 more scientific and effective data information. As a result, this research better overcame
19 the subjectivity of artificially determined index weights (Yu et al.,2018; Zhou et al.,
20 2016). D value is a dimensionless comprehensive evaluation constant of each tree
21 species. This evaluation was relatively objective and reliable. The PCA method and
22 membership function has offered advantages for the selection of suitable tree species

for afforestation in complex environments, and it is worth learning and applying. Tree species with strong drought resistance should be planted in environments with light dust in coal bases, those with better dust resistance could be selected for environments with serious dust and irrigation conditions, and those with good drought resistance and dust resistance could be planted in environments with high dust and water shortage. Although this experimental study was completed under the dust conditions of arid coal bases, it also had certain reference application value for the selection of tree species under the dust environment of other mining areas with the same aridity.

5. Conclusions

According to the results of this study, we drew the following conclusions.

1. Water consumption, RWC, RWD, conductivity, SOD content, and POD content had a relatively larger weight (>0.05) and therefore could be used as the main indices for the evaluation index system of drought resistance of tree species. The order of drought resistance was *Ammopiptanthus mongolicus* $>$ *Hedysarum scoparium* $>$ *Sabina vulgaris* $>$ *Caragana korshinskii* $>$ *Ulmus pumila* $>$ *Amorpha fruticosa* $>$ *Caryopteris mongholica* $>$ *Tamarix chinensis* $>$ *Elaeagnus angustifolia*.

2. Dust retention per unit leaf area, dust retention per unit leaf weight, stomatal conductance, main root system length, transpiration rate, photosynthetic rate, harm index, water use efficiency, and root biomass ratio had a relatively high weight (>0.05) and therefore could be used as the main indices to evaluate the dust resistance of tree species. The order of dust resistance was *Caragana korshinskii* $>$ *Amorpha fruticosa* $>$ *Sabina vulgaris* $>$ *Hedysarum scoparium* $>$ *Tamarix chinensis* $>$ *Ammopiptanthus*

mongolicus > *Ulmus pumila* > *Caryopteris mongholica* > *Elaeagnus angustifolia*.

3. Shoot length (dust retention), stomatal conductance (dust retention), crown breadth (dust retention), POD content (drought resistance), stem biomass ratio (dust retention), transpiration rate (drought resistance), SOD content (drought resistance), dust retention per unit weight (dust retention), photosynthetic rate (dust retention), water consumption (drought resistance), MDA content (drought resistance), intercellular CO₂ concentration (drought resistance), CAT content (drought resistance), and survival rate (drought resistance) had a relatively large weight (> 0.03) and could be used as the main indices for the comprehensive index system of drought resistance and dust resistance. The order of comprehensive capacity of drought resistance and dust resistance was *Caragana korshinskii* > *Ulmus pumila* > *Amorpha fruticose* > *Sabina vulgaris* > *Caryopteris mongholica* > *Ammopiptanthus mongolicus* > *Hedysarum scoparium* > *Tamarix chinensis* > *Elaeagnus angustifolia*.

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Fig. 1 Schematic diagram of potted planting test

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Table 1 Physicochemical properties of potted soil

Soil	pH	Conductivity (ms·cm ⁻¹)	Organic matter (g·kg ⁻¹)	Total Nitrogen (g·kg ⁻¹)	Total Phosphorus (g·kg ⁻¹)	Alkaline Nitrogen (g·kg ⁻¹)	Available Phosphorus (g·kg ⁻¹)	Rapidly available potassium (g·kg ⁻¹)
Content	8.81	1.50	1.97	0.09	0.11	41.9	7.69	120.30

Table 2 Evaluation standard for Leaves under dust resistance stress

Classification of harmed leaves (value)	Harmed symptoms
0	Leaves were green and normal.
1	The leaves were green with individual discolored spots or slight wrinkles and curls.
2	The fading area of the leaf reached 1/3 of the leaf area, and the leaves were obviously curled.
3	Above 3/4 area of the leaves were withered and severely curled.
4	The leaves were all withered or completely curled and easily broken.
5	Leaves fell off.

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Table 3 Symptoms of leaves after dust retention

Grades of harmed leaves							Grades of harmed leaves						
	0	1	2	3	4	5		0	1	2	3	4	5
<i>A. fruticosa</i>							<i>C. korshinskii</i>
<i>E. angustifolia</i>							<i>T. chinensis</i>
<i>U. pumila</i>							<i>C. mongolica</i>
<i>A. mongolicus</i>							<i>H. scoparium</i>
<i>S. vulgaris</i>

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Table 4 Tree species drought resistance evaluation index system

Target layer	Criterion layer	Weight	Index layer	Weight
Drought resistance of tree species	Growth status index	0.2867	Plant height	0.0409
			Ground diameter	0.0162
			Shoot length	0.0014
			Crown breadth	0.0401
			Main root length	0.0423
			Leaf biomass ratio	0.0041
			Stem biomass ratio	0.0462
			Root biomass ratio	0.0497
			Root shoot ratio	0.0457
			Soil water content	0.0156
	Water physiological index	0.2864	Leaf water content	0.0159
			Plant water content	0.0117
			Water consumption	0.0853
			RWC	0.0758
			RWD	0.0758
			Water retention capacity of leaves	0.0062
	Adaptability index	0.0458	Survival rate	0.0458
			Conductivity	0.0598
	Stress resistance index	0.1036	MDA content	0.0048
			Pro content	0.0390
			Transpiration rate Tr	0.0016
			Stomatal conductance Gs	0.0140
			Photosynthetic rate Pn	0.0235
			Intercellular CO ₂ concentration (Ci)	0.0327
	Photosynthetic physiological index	0.1051	Water use efficiency WUE	0.0332
			CAT content	0.0378
			SOD content	0.0620
			POD content	0.0726

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Table 5 Eigen vectors and percentages of accumulated contribution of principal components

Indices	Eigenvectors of the principal component indices						
	Principal	Principal	Principal	Principal	Principal	Principal	Principal
	component 1	component 2	component 3	component 4	component 5	component 6	component 7
Plant height	-0.0296	-0.0167	0.1638	0.0613	0.1840	-0.0282	-0.0136
Ground diameter	0.0866	-0.0408	-0.1085	0.0071	-0.0317	-0.2381	-0.1342
Shoot length	-0.0199	0.0631	0.1368	-0.0491	-0.1971	-0.1282	-0.0210
Crown breadth	-0.0341	0.0777	0.1458	0.1274	-0.0946	-0.0483	0.0953
Main root system length	-0.0043	0.1287	0.0336	0.1638	-0.0326	-0.2063	0.0148
Leaf biomass ratio	0.0181	0.0750	0.0316	-0.1306	-0.0633	-0.3175	0.1458
Stem biomass ratio	-0.1149	0.0497	0.0064	-0.1165	0.0228	0.0276	-0.0468
Root biomass ratio	0.0994	-0.0058	-0.0080	0.1731	-0.0509	-0.0107	-0.1089
Root shoot ratio	0.0969	-0.0124	-0.0100	0.1762	-0.0564	-0.0161	-0.1212
Soil water content	0.0753	-0.0253	-0.1101	-0.1765	0.0173	-0.0136	0.0676
Leaf water content	-0.0070	0.1403	-0.0899	0.0135	0.0128	0.1608	-0.2665
Plant water content	-0.0254	0.1063	-0.1661	0.0363	-0.0226	0.0048	0.0746
Water consumption	0.1157	0.0537	0.0518	0.0474	0.0531	0.0918	-0.0497
RWC	0.1075	-0.0257	0.0564	0.0373	0.0954	0.0589	0.2443
RWD	0.1075	-0.0257	0.0564	0.0373	0.0954	0.0589	0.2443
Water retention capacity of leaves	-0.0697	-0.0502	0.0190	0.1622	0.1218	0.1103	-0.2469
Survival rate	0.0807	0.1302	-0.0463	-0.0422	0.0160	-0.1245	0.0246
Conductivity	-0.0144	0.1531	0.0442	0.0744	0.0874	-0.0997	0.1900
Transpiration rate Tr	0.0333	0.0497	-0.1206	0.1346	-0.1792	0.0760	-0.0801
Stomatal conductance Gs	-0.0321	0.0560	-0.1625	-0.0406	0.0816	0.1121	0.2023
Photosynthetic rate Pn	-0.0825	0.0408	-0.0913	0.1548	-0.0599	-0.0177	0.1582
Intercellular CO ₂ concentration (Ci)	0.0763	0.0258	0.0476	-0.0604	-0.1902	0.2264	0.0341

Water use efficiency WUE	-0.1255	0.0285	0.0040	0.0500	0.0190	0.0030	0.0510
CAT content	0.0402	0.1390	-0.0197	-0.0786	0.1193	-0.0555	-0.2194
Pro content	0.0253	0.0943	0.0280	-0.0513	0.2152	-0.0977	-0.2859
SOD content	0.0435	0.0949	0.1261	-0.0890	-0.0126	0.2195	-0.0771
POD content	0.0152	0.1309	-0.0243	0.0457	0.1183	0.2077	0.2585
MDA content	-0.0233	0.0978	0.0796	-0.0898	-0.1830	0.1610	-0.0808
Characteristic root	7.5403	5.3132	4.5916	3.4607	3.0691	2.0017	1.5062
Contribution rate (%)	26.9298	18.9758	16.3984	12.3598	10.9612	7.1490	5.3794
Cumulative contribution rate (%)	26.9298	45.9056	62.3040	74.6638	85.6250	92.7740	98.1535

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Table 6 The value of each tree species' comprehensive index [CI_x], index weight, $U(X_j)$, value D

Variety	CI_1	CI_2	CI_3	CI_4	CI_5	CI_6	CI_7	$U(X_1)$	$U(X_2)$	$U(X_3)$	$U(X_4)$	$U(X_5)$	$U(X_6)$	$U(X_7)$	D value	Order
<i>A. mongolicus</i>	1.3695	4.3121	0.9762	1.4074	1.4322	-0.7877	-1.3474	0.9396	0.7144	0.4250	1.0000	0.5434	0.0291	0.3531	0.6750	1
<i>H. scoparium</i>	1.4709	4.4440	1.3248	0.0949	1.9232	-0.7942	-1.7625	1.0000	0.7599	0.6938	0.0000	0.6758	0.0242	0.2189	0.6265	2
<i>S. vulgaris</i>	1.4447	4.6920	0.7107	0.4419	3.2152	-0.6770	-2.4398	0.9844	0.8455	0.2203	0.2644	1.0243	0.1128	0.0000	0.6263	3
<i>C.korshinskii</i>	1.0167	4.7747	1.0031	0.6277	0.9730	0.1431	-1.8533	0.7295	0.8741	0.4458	0.4059	0.4196	0.7323	0.1896	0.6053	4
<i>U. pumila</i>	0.5939	3.2188	1.7219	1.1715	0.5932	0.2285	-0.4554	0.4778	0.3369	1.0000	0.8203	0.3171	0.7968	0.6414	0.5952	5
<i>A.fruticosa</i>	1.4506	2.9369	0.9179	0.9176	-0.5827	-0.2004	-0.1013	0.9879	0.2396	0.3801	0.6268	0.0000	0.4728	0.7559	0.5357	6
<i>C.mongholica</i>	0.4824	5.1395	1.5973	0.2515	0.8345	-0.8263	-1.7280	0.4114	1.0000	0.9039	0.1193	0.3822	0.0000	0.2301	0.5276	7
<i>T. chinensis</i>	0.7612	3.5288	0.4647	1.1120	-0.3445	0.4975	0.6539	0.5774	0.4440	0.0307	0.7749	0.0643	1.0000	1.0000	0.4817	8
<i>E.angustifolia</i>	-0.2085	2.2428	0.4249	1.1489	-0.5699	0.1084	-0.1466	0.0000	0.0000	0.0000	0.8031	0.0035	0.7061	0.7413	0.1935	9
Weight								0.2744	0.1933	0.1671	0.1259	0.1117	0.0728	0.0548		

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Table 7 Tree dust resistance evaluation index system

Target layer	Criterion layer	Weight	Index layer	Weight
Tree species dust resistance	Growth status index	0.3209	Plant height	0.0003
			Ground diameter	0.0108
			Shoot length	0.0370
			Crown breadth	0.0282
			Specific leaf weight	0.0475
			Main root system length	0.0752
			Leaf biomass ratio	0.0281
			Stem biomass ratio	0.0103
			Root biomass ratio	0.0581
			Root shoot ratio	0.0254
	Water physiological index	0.0450	Leaf water content	0.0203
			Plant water content	0.0247
	Dust retention	0.2435	Dust retention per unit leaf weight	0.1182
			Dust retention per unit leaf area	0.1253
	Stress resistance index	0.0621	Harm index	0.0621
			Transpiration rate	0.0738
	Photosynthetic physiological index	0.3285	Stomatal conductance	0.0829
			Photosynthetic rate	0.0636
			Intercellular CO ₂ concentration	0.0475
			Water use efficiency	0.0607

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Table 8 Eigenvectors and contribution rates of principal components of each index

Indices	Eigenvectors of the principal component indices					
	Principal component 1	Principal component 2	Principal component 3	Principal component 4	Principal component 5	Principal component 6
Plant height	0.025	-0.097	0.222	-0.016	-0.189	-0.237
Ground diameter	-0.114	0.041	0.191	-0.046	0.124	-0.086
Shoot length	0.121	-0.033	0.115	-0.129	-0.221	0.044
Crown breadth	-0.007	0.098	0.144	-0.202	-0.116	0.385
Specific leaf weight	-0.011	-0.087	0.119	0.126	0.419	0.013
Main root system length	0.09	-0.021	-0.045	0.064	0.168	0.454
Leaf biomass ratio	-0.058	-0.038	0.156	0.251	-0.048	0.106
Stem biomass ratio	0.124	-0.106	0.003	-0.158	-0.08	0.074
Root biomass ratio	-0.034	0.241	0.079	0.035	0.079	-0.115
Root shoot ratio	-0.056	0.226	0.065	-0.004	-0.019	-0.175
Leaf water content	-0.01	0.215	-0.101	-0.039	-0.131	0.19
Plant water content	0.003	0.136	-0.188	-0.143	0.073	-0.184
Dust retention per unit leaf weight	0.117	0.15	0.043	0.114	0.047	0.046
Dust retention per unit leaf area	0.123	0.122	0.034	0.095	0.146	0.176
Harm index	0.005	0.071	0.11	0.277	-0.224	0.081
Transpiration rate	0.149	0.014	0.017	-0.006	0.135	-0.23
Stomatal conductance	0.107	0.068	0.205	-0.07	-0.057	-0.106
Photosynthetic rate	0.085	0.017	0.145	-0.186	0.26	-0.024
Intercellular CO ₂ concentration	0.127	-0.02	-0.08	0.172	-0.133	-0.111
Water use efficiency	-0.136	-0.037	0.096	-0.12	0.002	0.2
Characteristic root	6.1	3.763	3.223	2.678	1.869	1.415
Contribution rate (%)	30.5	18.816	16.114	13.391	9.345	7.074
Cumulative contribution rate (%)	30.5	49.316	65.43	78.821	88.166	95.24

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Table 9 Comprehensive index values, weights, $U(X_j)$, D values and sorting of each species

Variety	CI_1	CI_2	CI_3	CI_4	CI_5	CI_6	$U(X_1)$	$U(X_2)$	$U(X_3)$	$U(X_4)$	$U(X_5)$	$U(X_6)$	D value	Order
<i>U. pumila</i>	3.0031	1.8346	3.6603	-1.3468	0.3893	-0.5618	0.3948	0.3987	0.3619	0.1573	1.0000	0.2148	0.4026	7
<i>Caragana korshinskii</i>	5.2477	1.7804	5.7658	-1.6624	-1.1033	-0.5922	1.0000	0.3765	1.0000	0.0000	0.0000	0.1942	0.5782	1
<i>Tamarix chinensis</i>	2.3636	1.8958	2.4664	-0.2503	0.2480	0.5203	0.2224	0.4239	0.0000	0.7040	0.9054	0.9491	0.4133	5
<i>Hedysarum scoparium</i>	2.1347	1.3665	4.7356	0.3436	-0.3226	-0.0822	0.1607	0.2066	0.6878	1.0000	0.5230	0.5402	0.4407	4
<i>Elaeagnus angustifolia</i>	1.5386	0.8630	2.4808	-0.3730	0.0335	0.2452	0.0000	0.0000	0.0044	0.6427	0.7616	0.7624	0.2225	9
<i>Caryopteris mongholica</i>	1.7574	1.4006	2.5960	0.0460	-0.3572	-0.0290	0.0590	0.2206	0.0393	0.8516	0.4999	0.5763	0.2807	8
<i>Sabina vulgaris</i>	2.0157	3.2996	4.5621	-0.4719	-0.4117	-0.8784	0.1286	1.0000	0.6352	0.5935	0.4633	0.0000	0.4752	3
<i>Amorpha fruticosa</i>	3.4645	1.7662	3.8878	-0.1139	0.1527	-0.6727	0.5192	0.3707	0.4308	0.7720	0.8415	0.1395	0.5139	2
<i>Ammopiptanthus mongolicus</i>	1.7080	1.6452	3.1189	0.2106	0.3171	0.5954	0.0457	0.3210	0.1978	0.9337	0.9516	1.0000	0.4105	6
Weight							0.3202	0.1976	0.1692	0.1406	0.0981	0.0743		

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Table 10 Comprehensive index values, weights, $U(X_j)$, D values and sorting of each species

Variety	CI_1	CI_2	CI_3	CI_4	CI_5	CI_6	$U(X_1)$	$U(X_2)$	$U(X_3)$	$U(X_4)$	$U(X_5)$	$U(X_6)$	D value	Order
<i>U. pumila</i>	3.0031	1.8346	3.6603	-1.3468	0.3893	-0.5618	0.3948	0.3987	0.3619	0.1573	1.0000	0.2148	0.4026	7
<i>Caragana korshinskii</i>	5.2477	1.7804	5.7658	-1.6624	-1.1033	-0.5922	1.0000	0.3765	1.0000	0.0000	0.0000	0.1942	0.5782	1
<i>Tamarix chinensis</i>	2.3636	1.8958	2.4664	-0.2503	0.2480	0.5203	0.2224	0.4239	0.0000	0.7040	0.9054	0.9491	0.4133	5
<i>Hedysarum scoparium</i>	2.1347	1.3665	4.7356	0.3436	-0.3226	-0.0822	0.1607	0.2066	0.6878	1.0000	0.5230	0.5402	0.4407	4
<i>Elaeagnus angustifolia</i>	1.5386	0.8630	2.4808	-0.3730	0.0335	0.2452	0.0000	0.0000	0.0044	0.6427	0.7616	0.7624	0.2225	9
<i>Caryopteris mongholica</i>	1.7574	1.4006	2.5960	0.0460	-0.3572	-0.0290	0.0590	0.2206	0.0393	0.8516	0.4999	0.5763	0.2807	8
<i>Sabina vulgaris</i>	2.0157	3.2996	4.5621	-0.4719	-0.4117	-0.8784	0.1286	1.0000	0.6352	0.5935	0.4633	0.0000	0.4752	3
<i>Amorpha fruticosa</i>	3.4645	1.7662	3.8878	-0.1139	0.1527	-0.6727	0.5192	0.3707	0.4308	0.7720	0.8415	0.1395	0.5139	2
<i>Ammopiptanthus mongolicus</i>	1.7080	1.6452	3.1189	0.2106	0.3171	0.5954	0.0457	0.3210	0.1978	0.9337	0.9516	1.0000	0.4105	6
Weight							0.3202	0.1976	0.1692	0.1406	0.0981	0.0743		

1 **Availability of data and materials**

2 The datasets used and/or analyzed during the current study are available from the
3 corresponding author on reasonable request.

5 **Abbreviations**

6 PCA method Principal component analysis method

7 SO₂ Sulfur dioxide

8 NO_x Nitric oxide

9 SOD Superoxide dismutase

10 POD Peroxidase

11 CAT Catalase

12 CO₂ Carbon dioxide

13 RWC Relative water content

14 MDA Malondialdehyde

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11

12 **contributions**

13 Xiaofang Zhu, Bing Cao and Xing Wang Conceived and designed the study. Xiaofang

14 Zhu, Siming Zhao and Hao Zhang conducted the field measurements. Xiaofang Zhu

15 collected data. Yongfeng Duan and Deping Gao provided field assistants. Xiaofang Zhu

16 wrote the paper, Bing Cao and Xing Wang reviewed the paper. All authors read and

17 approved the final manuscript.

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23 **Ethics declarations**

24 Ethics approval and consent to participate

25 Not applicable.

26 Consent for publication

-
- 1 Not applicable.
 - 2 Competing interests
 - 3 The authors declare that they have no competing interests.
 - 4

Figures

Figure 1

Schematic diagram of potted planting test