

Study of Leaf Venation Characteristics from 11 *Acer* Plants

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Abstract To explore the taxonomic significance of leaf venation characteristics in *Acer* plants, the herbarium specimens of 11 *Acer* plants were used as the materials. By preparing leaf venation specimens of 11 *Acer* plants, their leaf venation characteristics were observed and measured. Moreover, values were assigned to the leaf venation characteristics, and cluster analysis was conducted. The results showed that: the primary veins from 11 *Acer* plants were palmate or pinnate; the secondary veins were craspedodromous or true curved; the intersecondary veins were simple or compound; the tertiary veins were reticulate, terminal, or both; the interveinal areas were mostly well-developed, with a few being underdeveloped; the venules were absent, linear, or with 1 to 3 branches; the terminal venation of the leaf margin was mostly circular, with a few being incomplete. Cluster analysis based on the characteristics of leaf venation revealed that simple leaf types were more primitive, while compound leaf types were more evolved. The two types within Ser. Palmata were the most primitive; there was a close relationship between Sect. Platanoidea and Sect. Integrifolia; there was a close relationship between Sect. Ginnala and Sect. Lithocarpa; however, there was no support for a close relationship between *A. davidii* and *A. davidii* subsp. *grosseri*. The venation characteristics of *Acer* plants can provide new research materials for the classification of plants within the genus.

Keywords *Acer*, Leaf venation, Cluster analysis, Classification

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Acer is a widely distributed genus with high diversity. This genus comprises over 200 species, distributed across Asia, Europe, and the Americas. There are approximately more than 140 species in China^[1], making it the distribution center of *Acer* plants. Most *Acer* plants are renowned for their autumn foliage, possessing high ornamental value and occupying an important position in the autumn scenery of gardens. *Acer* plants are highly adaptable, tolerant to cold, drought, barren conditions, and alkaline soil, and have significant ecological benefits. The seeds of some species in *Acer* plants can be used to extract oil, and the tender leaves can be used to make tea, which has high economic value^[2]. Therefore, *Acer* plants have high prospects for development and utilization.

In 1753, Swedish scientist Carl Von Linne established the genus *Acer* in his *Species Plan-*

tarum. Since its establishment, many researchers have conducted studies on the taxonomic system of the genus *Acer* and the relationships among its various groups. However, due to the significant and highly complex phenotypic trait variation within the genus *Acer*, as well as the parallel and reverse evolution of most taxonomic traits across different clades, the taxonomic issues and phylogenetic relationships within the genus have not been well resolved^[3]. Venation refers to the arrangement and distribution pattern of veins in leaves, which is a stable characteristic in plant morphology and less affected by environmental factors. The characteristics of leaf venation have been widely applied in the identification of ancient plants and modern plant classification, successfully solving many taxonomic challenges^[4-5]. Currently, there are no reports on the leaf venation of *Acer*. In

this paper, by observing and conducting cluster analysis on the leaf venation of 11 *Acer* plants, it determined the taxonomic significance of leaf venation in *Acer* plants, with the hope of providing new evidence for the classification of *Acer* plants.

1 Materials and methods

1.1 Test materials

The test materials consisted of 11 *Acer* plants collected from the Luoyang area, as detailed in Table 1.

1.2 Test methods

The specimen preparation followed the venation method described by Liu Lixia et al^[6]. The prepared leaf venation specimens were observed, scanned, and photographed using a stereomicroscope. The terminology for describing leaf venation followed that of

Table 1 Test materials

No.	Name of test materials	Taxonomic status	Collection site
1	<i>A. truncatum</i>	Ser. Platanoidea of Sect. Platanoidea	Kaiyuan Campus, Henan University of Science and Technology
2	<i>A. pictum</i> subsp. <i>mono</i>	Ser. Platanoidea of Sect. Platanoidea	Botanical Garden of the Sui and Tang City Ruins
3	<i>A. buergerianum</i>	Ser. Trifida of Sect. Integrifolia	Xiyuan Park
4	<i>A. palmatum</i> ‘Atropurpureum’	Ser. Palmata of Sect. Palmata	Kaiyuan Campus, Henan University of Science and Technology
5	<i>A. duplicatoserratum</i> var. <i>chinese</i>	Ser. Palmata of Sect. Palmata	Botanical Garden of the Sui and Tang City Ruins
6	<i>A. sterculiaceum</i> subsp. <i>franchetii</i>	Ser. Lithocarpa of Sect. Lithocarpa	Muzhaling
7	<i>A. negundo</i>	Ser. Negundo of Sect. Negundo	Botanical Garden of the Sui and Tang City Ruins
8	<i>A. griseum</i>	Ser. Grisea of Sect. Trifoliata	Botanical Garden of the Sui and Tang City Ruins
9	<i>A. tataricum</i> subsp. <i>ginnala</i>	Ser. Tatarica of Sect. Ginnala	Laojieling, Funiu Mountain
10	<i>A. davidii</i>	Ser. Crataegifolia of Sect. Macrantha	Muzhaling
11	<i>A. davidii</i> subsp. <i>grosseri</i>	Ser. Crataegifolia of Sect. Macrantha	Chongdu Valley

Sun Qigao et al^[7]. 15 leaf shape and venation features were selected for measurement, description, and assignment of values. The specific assignment coding results were shown in Table 2.

2 Results and analysis

2.1 Morphological analysis of venation

There was significant variation in the venation patterns observed among the 11 *Acer* plants. As can be seen from Fig.1, the leaf veins from the 11 *Acer* plants fell into two categories:

palmate veins and pinnate veins. Among them, the single-leaf type had palmate veins, while *A. negundo* and *A. griseum*, which had odd-pinnate compound leaves, had pinnate veins.

The primary veins of various species exhibited diverse degrees of thickness. The primary veins of *A. pictum* subsp. mono, *A. duplicatoserratum* var. chinese, *A. griseum*, and *A. davidii* subsp. grosseri were relatively thick; those of *A. truncatum*, *A. negundo*, *A. tataricum* subsp. ginnala, and *A. davidii* were thinner; and those of other species fell in between.

They run straight with a few bends, becoming thicker near the leaf base and thinner at the leaf tip. The tail of the primary vein of the leaf blade was curved, with one to multiple pairs of lateral primary veins. The secondary veins were mostly 3 to 9 pairs, with the secondary veins of *A. negundo* reaching 8 to 11 pairs; they were straight-branching or true curved, reaching the margin, and some form secondary vein loops, with angles being acute, right, or obtuse. There were simple or compound intersecondary veins, some of which had lateral secondary veins.

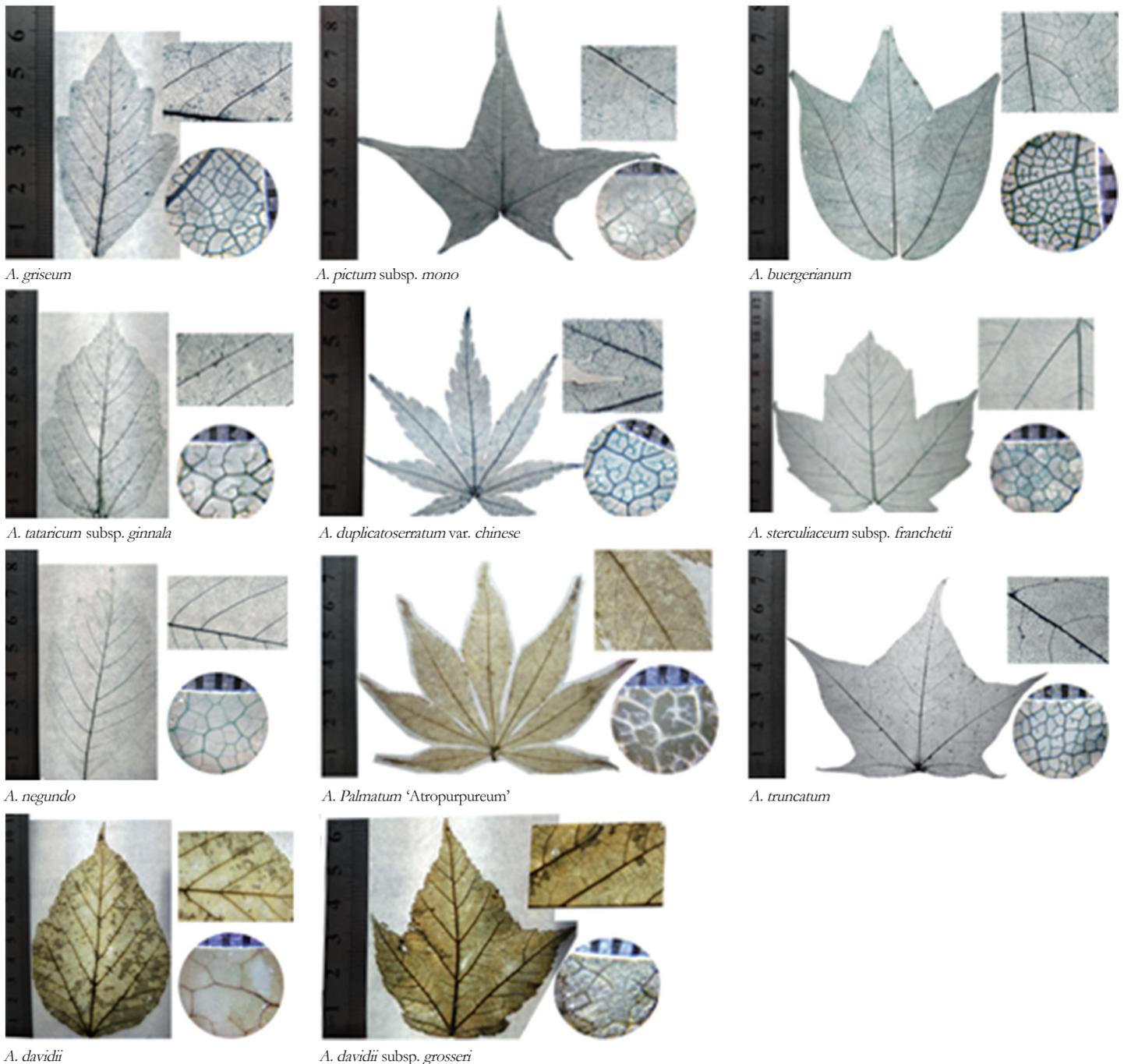


Fig.1 Leaf morphology and venation characteristics from 11 *Acer* plants

Table 2 Traits and codes

No.	Trait	Trait type	Code
1	Leaf lobe	Multivariate traits	No fissure “0”; shallow fissure “1”; deep fissure “2”
2	Neuration type	Binary trait	Palmate veins “0”; pinnate veins “1”
3	Main vein	Multivariate traits	Thin “0”; average “1”; thick “2”
4	Secondary vein ring	Binary trait	No “0”; Yes “1”
5	Secondary veins’ angle	Multivariate traits	Narrow “0”; moderate “1”; wide “2”
6	Tertiary vein	Multivariate traits	Random reticular pattern “0”; square reticular pattern “1”; and top type “2”
7	Interveinal area composition	Binary trait	Grade 3–4 vein: “0”; Grade 4–5 vein: “1”
8	Interveinal area development	Binary trait	Not complete “0”; complete “1”
9	Interveinal area length	Quantitative trait	–
10	Interveinal area width	Quantitative trait	–
11	Leaf margin ultimate vein	Binary trait	Incomplete “0”; complete “1”
12	Central lobe leaf tip	Multivariate traits	Blunt “0”; short and pointed “1”; gradually tapering “2”; gradually narrowing “3”; acute “4”
13	Lateral lobe leaf tip	Binary trait	None “0”; blunt “1”
14	Entire leaf margin	Binary trait	Yes “0”; No “1”
15	Leaf shape	Binary trait	Single leaf “0”; compound leaf “1”

Tertiary veins were reticular (mostly square-shaped, with a few being random), as well as top-type (bifurcated, straight, wavy, curved, etc.), or a combination of both. The interveinal zones formed by tertiary veins and quaternary veins, or quaternary veins and quinary veins, were mostly fully developed, while those of *A. duplicatoserratum* var. *chinese*, *A. negundo*, and *A. tataricum* subsp. *ginnala* were not fully developed. The venules were linear or had 1 to 3 branches, with a few having no venules. The terminal venation of the leaf margin of *A. truncatum*, *A. buergerianum*, *A. sterculiaceum* subsp. *franchetii*, *A. griseum*, *A. tataricum* subsp. *ginnala*, and *A. davidii* was incomplete, while the terminal venation of the leaf margin of other species was circular, with blind veins. Based on the leaf venation characteristics from the 11 *Acer* plants, a classification retrieval table was compiled, as detailed in Table 3.

2.2 Cluster analysis of leaf venation from 11 *Acer* plants

2.2.1 R-type cluster analysis. R-type clustering was conducted on 15 traits of 11 *Acer* plants using Pearson correlation. The clustering results were shown as Fig.2. As can be seen from Fig.2, the correlation between most traits was not strong, but there was a strong correlation between leaf vein type and leaf shape. Among the 11 *Acer* plants, whether they are species, subspecies, varieties, or cultivars, the type of simple leaves all exhibited palmate veins, while the type of compound leaves all exhibited pinnate veins. These two traits may exhibit a phenomenon of co-evolution in *Acer* plants. Therefore, when conducting Q-type cluster analysis, to avoid simultaneously utilizing two correlated traits to increase the weights and affect the research results, only one of these two traits

Table 3 Morphological classification and retrieval of leaf venation from 11 *Acer* plants

1. Pinnate vein	
2. Mixed type of craspedodromous vein.....	<i>A. negundo</i>
2. Simple type of craspedodromous vein.....	<i>A. griseum</i>
1. Palmate vein	
3. Palmately parted	
4. Palmate with 7 lobes, 7 main veins, relatively thick.....	<i>A. duplicatoserratum</i> var. <i>chinese</i>
4. Palmate with 5–7 lobes, 5–7 main veins, generally uniform in thickness.....	<i>A. palmatum</i> ‘ <i>Atropurpureum</i> ’
3. Palmate, shallowly lobed or undivided	
5. With secondary vein rings	
6. Interveinal zone is composed of quaternary veins and quinary veins.....	<i>A. buergerianum</i>
6. Interveinal zone is composed of tertiary veins and quaternary vein	
7. The main vein is relatively thin, and the terminal veins on the leaf margin are incomplete.....	<i>A. truncatum</i>
7. The main vein is thick, and the terminal veins of the leaf margin are ring-shaped, with small veins	
.....	<i>A. pictum</i> subsp. <i>mono</i>
5. Without secondary vein rings	
8. Development of the interveinal zone is incomplete.....	<i>A. tataricum</i> subsp. <i>ginnala</i>
8. Development of the interveinal zone is complete	
9. The terminal vein of leaf margin is ring-shaped, with veinlets.....	<i>A. davidii</i> subsp. <i>grosseri</i>
9. The terminal vein of leaf margin is incomplete	
10. Small veins are none, linear or 2–3 times branched.....	<i>A. sterculiaceum</i> subsp. <i>franchetii</i>
10. Small veins are linear or 2–3 times branched.....	<i>A. davidii</i>

needed to be selected.

2.2.2 Q-type cluster analysis. Based on the results of R-type cluster analysis, after removing the leaf shape traits, Q-type cluster analysis was performed on 11 *Acer* plants using the remaining 14 traits. Q-type cluster analysis employed Euclidean distance and the between-group linkage method. The cluster analysis results were shown as Fig.3.

As can be seen from Fig.3, at a distance of 20, *A. negundo* with compound leaf traits consisting of 3 to 7 leaflets was isolated; at a distance of 15, *A. griseum* with compound leaf traits consisting of 3 leaflets was also isolated, while the other 9 *Acer* plants with simple leaf traits were clustered together. The early convergence of *A. palmatum* ‘*Atropurpureum*’ and *A. duplicatoserratum* var. *chinese* indicated that they had a close genetic relationship. The other seven single-leaf *Acer* plants, excluding

Ser. Palmata, clustered together in the middle. *A. buergerianum*, *A. pictum* subsp. *mono*, *A. truncatum*, and *A. davidii* subsp. *grosseri* clustered together, while *A. sterculiaceum* subsp. *franchetii*, *A. tataricum* subsp. *ginnala*, and *A. davidii* clustered together, indicating a close relationship between Sect. Platanoidea and Sect. Integrifolia; Sect. Ginnala and Sect. Lithocarpa were closely related; however, *A. davidii* subsp. *grosseri* and *A. davidii*, which belonged to Ser. Crataegifolia, were not clustered together.

3 Discussion

The classification of *Acer* plants has evolved from traditional morphological classification^[8] and pollen micromorphology^[9] to molecular marker technology^[3]. Different classification methods often yield different classification results. Most classification results, including this study^[8-9], generally support the taxonomic system of the

genus *Acer* in Flora of China, but molecular marker studies have drawn different conclusions regarding the phylogenetic relationships of individual species.

In this study, *A. negundo* and *A. griseum* with compound leaf traits were grouped separately, while the other nine *Acer* plants with simple leaf traits were grouped together. This not only supports the establishment of Sect. Negundo and Sect. Trifoliata in the systematic classification of the *Acer* genus, but also indicates that these compound leaf types are more evolved than simple leaf types. It is

considered appropriate to place them last in the systematic classification^[1]. The suggestion by Lin Li^[5] to downgrade Sect. Trifoliata to a series and merge it into Sect. Integrifolia is not supported.

The early convergence of *A. palmatum* ‘Atropurpureum’ and *A. duplicatoserratum* var. *chinese* indicated that they had a close genetic relationship. In the Flora of China, *A. duplicatoserratum* var. *chinese* was recorded as a variant of *Acer palmatum* Thunb., *Acer palmatum* var. *thunbergi*, and its leaf shape and vein characteristics are more similar to those of *A. palmatum* Thunb. than to *Acer*

duplicatoserratum Hayata. The clustering results supported the reclassification of *A. duplicatoserratum* var. *chinese* as *A. palmatum* var. *thunbergi*. Both species were located at the top of the clustering diagram, supporting the research conclusion of Tian Xin et al.^[10] that Sect. Palmata is the most primitive.

In this study, *A. buergerianum*, *A. pictum* subsp. *mono*, *A. truncatum*, and *A. davidii* subsp. *grosseri* were grouped together, while *A. sterculiaceum* subsp. *franchetii*, *A. tataricum* subsp. *ginnala*, and *A. davidii* were grouped together. This indicated that Sect. Platanoidea and Sect. Integrifolia were closely related. Sect. Ginnala and Sect. Lithocarpa were also closely related, which did not support the conclusion drawn by Lin Li that Sect. Platanoidea and Sect. Lithocarpa were closely related based on pollen morphology^[5]. Although *A. davidii* subsp. *grosseri* and *A. davidii* are of the same family, the former has lobed leaves. Main vein is thick, and there are 4 to 7 pairs of secondary veins. Tertiary veins form a square net pattern, veins at the edge of the leaf margin are circular, with blind vein. However, the latter has undivided leaves. Main vein is thin, and there are 7 to 9 pairs of secondary veins. Tertiary veins are straight and top type, and terminal veins at the edge of the leaf margin are incomplete. The two species differ significantly in their venation patterns. In the clustering results, the two were not clustered together, and the leaf venation characteristics did not support a close phylogenetic relationship between them. However, whether it is necessary to re-adjust their taxonomic positions requires more taxonomic evidence.

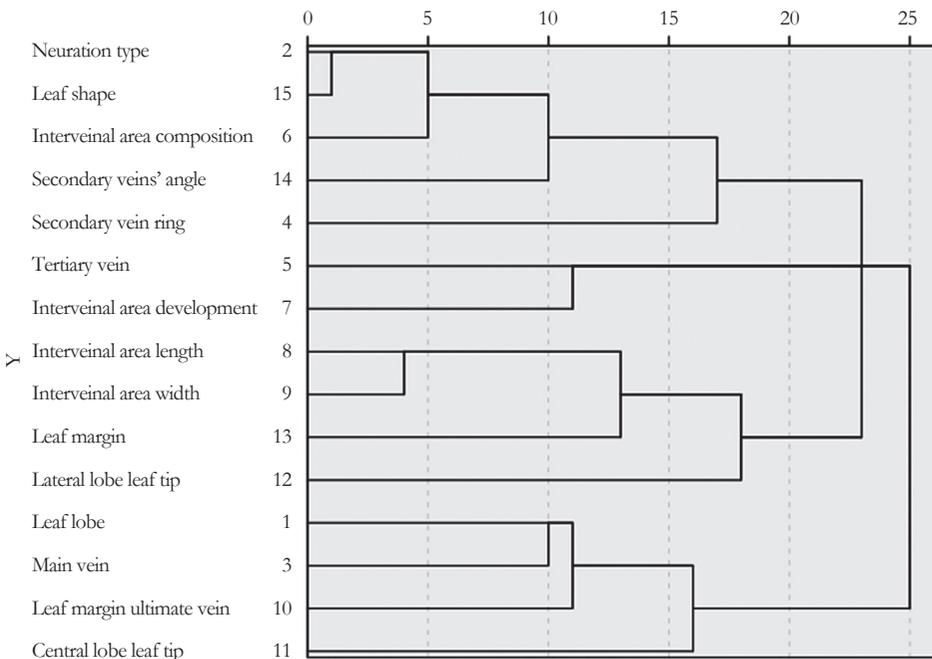


Fig.2 R-type cluster analysis results of 15 leaf venation traits

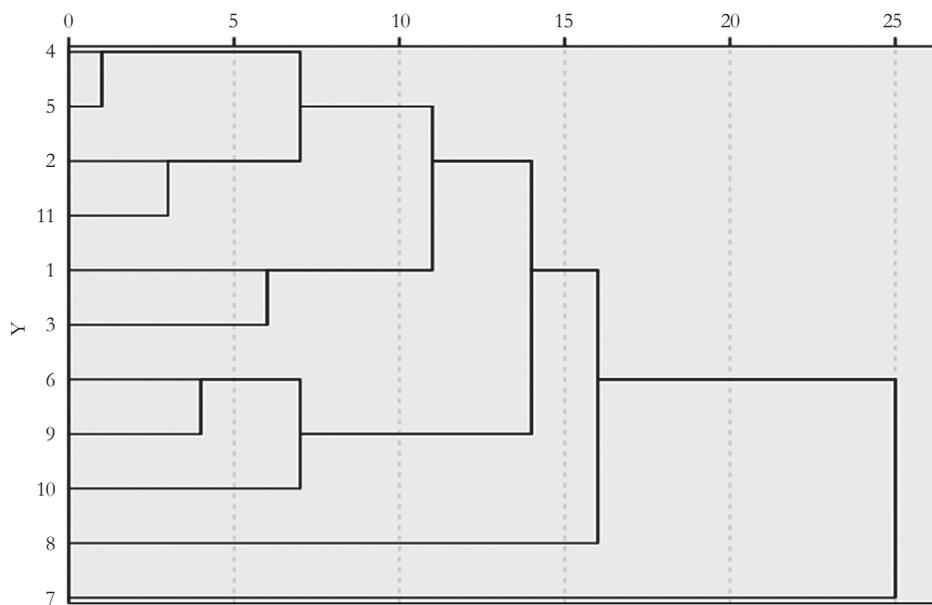


Fig.3 Q-type cluster results of 11 *Acer* plants

4 Conclusions

The leaf veins of *Acer* plants fall into two types: palmate veins and pinnate veins. Generally, simple leaves exhibit palmate veins, while compound leaves exhibit pinnate veins. The primary veins exhibit varying degrees of coarseness, with some straight and a few curved. The secondary veins are mostly 3 to 9 pairs, with straight branches or true curved shapes, reaching the margin; there are simple or complex inter-secondary veins. The tertiary veins are reticular, apical, or both; the interveinal areas are mostly fully developed. Based on the characteristics of the venation patterns of *Acer* plants, it is concluded that the simple leaf type is more primitive, while the compound leaf type is more evolved. The two types within Ser. Palmata are

(To be continued in P48)

lies in the unclear responsibility chain and unstable cooperation mechanism. Therefore, it is necessary to take streets as the leading unit to establish a regular coordination mechanism among the subway operator, the urban management department, enterprises of shared bicycles, and the property management unit. The management responsibilities of each party within the station, outside the station, and within the red line boundary should be clearly defined to achieve quantifiable responsibilities and traceable work.

Enterprises of shared bicycles should be included in the local assessment system. The execution rate of electronic fences, vehicle dispatch efficiency, and parking order maintenance should be as evaluation indicators to form a closed system, in which enterprises have motivation and local authorities can supervise^[7].

Based on the mechanism of “responding to the people’s call”, it is also necessary to promote governance to shift from responding to complaints immediately to taking action before problems arise. A warning mechanism should be established based on 12345 complaint data, parking saturation monitoring, and passenger flow data. During peak hours, temporary parking areas should be set up in advance, and managers should be dispatched, or key areas should be directed to enhance the initiative of governance.

Meanwhile, residents, volunteers, and community property management should be encouraged to participate in daily order maintenance and the co-construction of small-scale facilities, forming a collaborative governance pattern involving the government, enterprises, and communities, and advancing problem governance from short-term remediation to long-term co-governance.

4 Conclusions and outlook

The prominent issue of non-motorized vehicle parking at Pingguoyuan Metro Station is not caused by a single factor, but is the result of insufficient facilities, tight space, lack of management, and the growing public demand. It is found that the parking areas around the station are limited in quantity and scattered in layout, making it difficult to match the peak-hour demand; each department is responsible for a separate part, which has led to fragmented governance, and rectification actions are more inclined to be temporary responses, lacking sustainability; public demands truly reflect problems such as unsafe space, inconvenient vehicle retrieval, and inadequate management. Based on this, the research proposes to promote the parking order at the station from “chaotic management” to “normal governance” by improving parking facilities, implementing vehicle and pedestrian separation, establishing a collaborative governance mechanism, and moving “responding immediately to complaints” forward to “early warning governance”.

This research still has limitations: firstly, the data are mainly from on-site observations and complaint information, and there is a lack of precise statistics on passenger flow, parking usage rate, etc.; the analysis of supply and demand and time changes is relatively shallow, and the technical feasibility and implementation cost have not been fully considered. Secondly, it focuses on a single subway hub, and the station is not compared with other stations. Moreover, a generalizable governance model that can be promoted has not been formed yet. In the future, AI recognition and big data technologies can be introduced to build a non-motorized vehicle management system, expand the research

scope, and form an adaptation plan for “aging urban area + transfer stations”.

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(Continued from P44)

the most primitive There is a close relationship between Sect. Platanoidea and Sect. Integrifolia. There is also a close relationship between Sect. Ginnala and Sect. Lithocarpa. However, there is no support for the close relationship between *A. davidii* and *A. davidii* subsp. *grosseri*. The characteristics of leaf venation have taxonomic significance at the species and infraspecific levels of *Acer* plants.

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