

The identification tool of *Digiphyll* – a short introduction

The identification tool of *Digiphyll* is based on check-boxes assigned to a number of leaf morphological characters (or traits). Individual leaf characters are defined systematically based on qualitative and quantitative properties (character states). These character states can be simply binary or hierarchically nested. The identification process in *Digiphyll* follows these levels via hierarchical check boxes: if the state of a leaf character is identified for the considered fossil, the corresponding check-box is clicked. For example, the character “leaf margin” can be described at the highest level by just two states, untoothed or toothed. From the level toothed margin different types of teeth can be distinguished: the types crenate or dentate, as the next hierarchical level.

- Basically, all listed leaf morphological characters are referred to whole leaves or in the case of compound leaves on their leaflets.
- The considered leaf morphological characters are arranged into several categories. Each of these categories contains one or more characters with several character states, which can be hierarchically structured. The transition to a lower hierarchical level is indicated by “>”, where the number of “>” corresponds to the order of the hierarchical level (e.g., “>>” means 3rd hierarchical level).

In the following, the macroscopic features are divided into two sections:

- **A:** Leaf morphological characters
- **B:** Leaf venation characters

The leaf morphological characters (A) are arranged starting from the leaf base (i.e. petiole) proceeding upwards to the leaf tip (apex). Leaf vein characters (B) are arranged from lowest order (primary veins) progressing to the highest order (i.e. secondary and tertiary veins).

The character system used in *Digiphyll* follows the “*Manual of Leaf Architecture*”, *Ellis et al., The New York Botanical Garden Press, 2009*. The concept of the identification process applied in *Digiphyll* will be summarised in the following. For a more detailed description of the traits, see *Ellis et al. (2009)*.

A. Leaf morphological characters

The considered leaf morphological characters are arranged into **nine** categories.

- A-1. Leaf petiole
- A-2. Leaf organisation
- A-3. Leaf shape
- A-4. Leaf base angle
- A-5. Leaf base shape
- A-6. Leaf apex angle
- A-7. Leaf apex shape
- A-8. Leaf margin
- A-9. Leaf teeth

A-1. Leaf petiole

The petiole is the stalk of a single leaf. In case of compound leaves, the petiolule (stalk) of a leaflet (= subunit of a compound leaf) is treated as “petiole”. There are **five** character states describing the features of the leaf petiole.

#	Code	Character State	Description
1	A-1.1	unknown or absent	Petiole cannot be recognised.

#	Code	Character State	Description
2	A-1.2	present	Petiole or parts of it are visible.
3	A-1.2.1	> short	Petiole or parts of it are < 5 mm.
4	A-1.2.2	> long	Petiole or parts of it are > 5 mm.
5	A-1.2.3	> uncertain	Petiole length cannot be determined exactly.

A-2. Leaf organisation

The leaf organisation describes the divisions of the leaf blade (or lamina): undivided or subdivided. There are **four** character states describing the leaf organisation of one or more lamina subunits (leaflets).

#	Code	Character State	Description
1	A-2.1	simple	The leaf consists of a single lamina.
2	A-2.2	compound	The leaf consists of two or more leaflets.
3	A-2.2.1	> palmately compound	The leaf has more than two separate leaflets attached to a petiole.
4	A-2.2.2	> pinnately compound	The leaf has more than two leaflets arranged along a rachis.

A-3. Leaf shape

The leaf shape is the overall form of the lamina in terms of simple geometric forms. There are **10** character states describing the leaf shape. For convenience, we will use “leaf”, “leaf blade” and “leaf lamina” synonymously.

#	Code	Character State	Description
1	A-3.1	elliptic	The widest part of the leaf is in the middle one-fifths.
2	A-3.2	obovate	The widest part of the leaf is in the distal two-fifths.
3	A-3.3	ovate	The widest part of the leaf is in the proximal two-fifths.
4	A-3.4	oblong	The opposite margins are roughly parallel for at least the middle one-third.
5	A-3.5	linear	The length-to-width ratio of the leaf is > 10:1, regardless of the position of the widest part of the leaf.
6	A-3.6	lobed	The leaf is lobed.
7	A-3.6.1	> pinnately lobed	Major veins of the lobes are formed by costal (arising directly from major vein) secondary veins.
8	A-3.6.2	> palmately lobed	Major veins of the lobes are primary veins that arise from the base of the leaf.
9	A-3.6.3	> bilobed	Leaf has two lobes.
10	A-3.7	other	Leaf outlines which cannot be assigned to one of the shape classes above.

A-4. Leaf base angle

The leaf base is defined by the proximal 25% of the lamina. There are **four** character states describing the leaf base angle.

#	Code	Character State	Description
1	A-4.1	acute	Lamina base angle is $< 90^\circ$.
2	A-4.2	obtuse	Lamina base angle is $90^\circ < x < 180^\circ$.
3	A-4.3	reflex	Lamina base angle is $180^\circ < x < 360^\circ$.
4	A-4.4	circular (peltate)	Lamina base angle is $> 360^\circ$; petiole is attached inside the leaf lamina.

A-5. Leaf base shape

The leaf base is defined for the proximal 25% of the lamina. There are **11** character states describing the shape of the leaf base.

#	Code	Character State	Description
1	A-5.1	leaf base shape without basal extension	The lamina does not reach beyond the point where the petiole is attached to the major vein.
2	A-5.1.1	> cuneate (straight)	The margin between the base and the proximal 25% of the lamina has no significant curvature.
3	A-5.1.2	> rounded	The leaf margin between the base and the proximal 25% of the lamina forms a smooth arc.
4	A-5.1.3	> truncate	The base terminates abruptly as if cut perpendicularly to the major vein.
5	A-5.1.4	> concavo-convex	The margin between the base and the proximal 25% of the leaf is concave basally and convex apically.
6	A-5.1.5	> complex	There are more than two inflection points in the curve of the margin between the base and the next 25% of the leaf length.
7	A-5.1.6	> decurrent	The base of the lamina margin shows a gradual (asymptotic) course towards the petiole.
8	A-5.2	leaf base shape with basal extension	The lamina reaches below the point where the petiole is attached to the major vein.
9	A-5.2.1	> cordate	The leaf base forms a single sinus, with the deepest point of the sinus at the insertion point of the petiole.
10	A-5.2.2	> sagittate	The lamina base shows the shape of an arrowhead.
11	A-5.2.3	> hastate	The leaf base has two narrow lobes whose tips are directed outwards, with an angle of $90^\circ - 125^\circ$ to the major vein.

6. Leaf apex angle

The leaf apex (= leaf tip) occupies the distal 25% of the lamina. There are **three** character states describing the leaf apex angle.

#	Code	Character State	Description
1	A-6.1	acute	Lamina apex angle is $< 90^\circ$.
2	A-6.2	obtuse	Lamina apex angle is $90^\circ < x < 180^\circ$.
3	A-6.3	reflex	Lamina apex angle is $180^\circ < x < 360^\circ$.

7. Leaf apex shape

The leaf apex is defined by the distal 25% of the lamina. There are **seven** character states describing the shape of leaf apex.

#	Code	Character State	Description
1	A-7.1	attenuate (straight)	Margins straight or only slightly concave, gradually tapering to a narrow acute apex.
2	A-7.2	acuminate	Tip gradually tapering to a sharp point, with both apical opposite leaf margin parts inwardly curved.
3	A-7.3	rounded	The margin forms a smooth arc across the lamina apex.
4	A-7.4	emarginate	Apex sinus is smaller than 25% of lamina length.
5	A-7.5	lobed	Apex sinus is larger than 25% of lamina length.
6	A-7.6	truncate	Apex terminates abruptly as if cut perpendicularly to the major vein or nearly so.
7	A-7.7	convex	Margin between apex and distal 0.25% of lamina the outwardly curved.

8. Leaf margin

For the margin of the lamina there are **four** character states.

#	Code	Character State	Description
1	A-8.1	untoothed	The leaf margin has no teeth.
2	A-8.2	toothed	The leaf margin has at least one tooth.
3	A-8.2.1	> crenate	The majority of the teeth show a rounded tip.
4	A-8.2.2	> dentate	The majority of the teeth have a pointed tip.

9. Leaf teeth

Different tooth characters are used to describe the features of the leaf teeth. There are **five** characters with overall **12** character states of leaf teeth.

#	Code	Character State	Description
1a	A-9.1.1	order of teeth: simple order (first order)	All teeth are the same size or vary in size continuously.
1b	A-9.1.2	order of teeth: double (second order) or higher orders	Teeth are at least of two distinct sizes.
2a	A-9.2.1	tooth density: dense	More than 5 teeth per centimeter, measured in the middle 50% of the lamina.

#	Code	Character State	Description
2b	A-9.2.2	tooth density: not dense	Up to 5 teeth per centimeter, measured in the middle 50% of the lamina.
3a	A-9.3.1	tooth size: small	See illustration.
3b	A-9.3.2	tooth size: big	See illustration.
4a	A-9.4.1	tooth apex shape: acute	Flanks of tooth form a pointed tip.
4b	A-9.4.2	tooth apex shape: rounded	Flanks of tooth form a rounded tip.
4c	A-9.4.3	tooth apex shape: glandular	Gland is present in the tooth apex.
4d	A-9.4.4	tooth apex shape: spinose	Tooth apex is distinctly elongated.
5a	A-9.5.1	tooth sinus shape: acute	Tooth sinus is pointed.
5b	A-9.5.2	tooth sinus shape: rounded	Tooth sinus is rounded.

B. Leaf venation

All morphological traits describing the venation are divided into **five** sections. Each of these sections contains one or more characters with several character states. The vein order is defined by the gauge (= vein diameter).

- 1. Primary vein framework
- 2. Secondary vein framework
- 3. Intramarginal veins
- 4. Intersecondary veins
- 5. Tertiary vein framework

1. Primary vein framework

Primary veins (also “major veins” or “1° veins”) are veins of the largest gauge. There are **12** characters states describing the features of the 1° venation.

#	Code	Character State	Description
1	B-1.1	pinnate	The leaf or leaflet has a single 1° vein.
2	B-1.2	palmate	The leaf has three or more large basal veins, and at least two of them are primaries (i.e. the diameter of at least one of the narrower veins is > 75% of the diameter of the thickest vein).
3	B-1.2.1	> actinodromous	Three or more 1° veins diverge radially from a single point.
4	B-1.2.1.1	>> basal actinodromous	All 1° veins radiate from the petiolar insertion point.
5	B-1.2.1.2	>> suprabasal actinodromous	Three or more 1° veins radiate from a point distal to the petiolar insertion point.
6	B-1.2.2	> palinactinodromous	Three or more 1° veins diverge in a series of branches rather than from a single point.
7	B-1.2.3	> acrodromous	Three or more 1° veins originate from a point and run in convergent arches toward the leaf apex.
8	B-1.2.3.1	>> basal acrodromous	All 1° veins radiate from the petiolar insertion point.
9	B-1.2.3.2	>> suprabasal acrodromous	Three or more 1° veins originate from a point distal to the petiolar insertion point.

#	Code	Character State	Description
10	B-1.2.4	> flabellate	Several to many equally fine basal veins diverge radially at low angles to each other and branch distally.
11	B-1.2.5	> parallelodromous	Multiple parallel 1° veins originate collaterally at the lamina base and converge toward the leaf apex (typically only in monocot leaves).
12	B-1.2.6	> campylodromous	Multiple parallel 1° veins originate collaterally at or near the lamina base and run in strongly recurved arches that converge toward the leaf apex (typically only in monocot leaves).

2. Secondary vein framework

Secondary veins (also “2° veins”) show the next level of gauge (narrower compared to primary veins). There are **11** characters states describing the features of 2° venation.

#	Code	Character State	Description
1	B-2.1	2° veins reach margin	Major 2° or their branches reach the margin.
2	B-2.1.1	> craspedodromous	2° veins terminate at the margin or at the marginal vein. Mostly, craspedodromous leaves show a toothed margin.
3	B-2.1.2	> semicraspedodromous	2° veins branch near the margin; one of the branches terminates at the margin and the other joins the superjacent secondary.
4	B-2.2	2° veins do not reach margin	2° veins and their branches do not reach the margin and lose gauge (become narrower) by attenuation.
5	B-2.2.1	> eucamptodromous	2° veins connect to superjacent secondaries via tertiaries without forming marginal loops.
6	B-2.2.1.1	>> basal eucamptodromous	All eucamptodromous secondaries arise from the base of the leaf.
7	B-2.2.2	> cladodromous	2° veins ramify freely.
8	B-2.3	2° veins form loops and do not reach margin	Major 2° form loops and do not reach the margin.
9	B-2.3.1	> brochidodromous	2° veins join in a series of prominent arches or loops without becoming narrower.
10	B-2.3.2	> weak brochidodromous	Principally a brochidodromous pattern, but veins become narrower in the loop region.
11	B-2.4	other	Major 2° course is different to previous types or mixed.

3. Intramarginal veins

When present intramarginal veins run closely parallel to the leaf margin without becoming much narrower. There are **two** characters states describing intramarginal veins.

#	Code	Character State	Description
1	B-3.1	intramarginal veins present	Intramarginal veins are present.

#	Code	Character State	Description
2	B-3.2	intramarginal veins absent	Intramarginal veins are not present.

4. Intersecondary veins

When present intersecondary veins have courses similar to those of the secondaries, but are generally shorter and their diameter is between major secondaries and tertiaries. There are **two** characters states describing intersecondaries.

#	Code	Character State	Description
1	B-4.1	intersecondary veins present	Intersecondary veins are present.
2	B-4.2	intersecondary veins absent	Intersecondary veins are not present.

5. Tertiary vein framework

The next level of the venation system is represented by tertiary veins (also 3° veins) (narrower than secondary veins). There are **five** characters states describing the features of 3° venation.

#	Code	Character State	Description
1	B-5.1	percurrent	3° veins cross between adjacent secondaries.
2	B-5.1.1	> opposite	Majority of tertiaries cross between adjacent secondaries parallel paths without branching.
3	B-5.1.2	> alternate	Majority of tertiaries cross between adjacent secondaries regular offsets (with abrupt angular discontinuities) near the middle of the intercostal area.
4	B-5.1.3	> mixed	3° veins have both opposite and alternate percurrent courses.
5	B-5.2	reticulate	3° veins connect to other tertiary veins or secondary veins to form a net.