Original Article

Cladistic analysis of the section *Adonanthe* under genus *Adonis* L. (Ranunculaceae) from East Asia

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ABSTRACT

Cladistic analysis was conducted for 11 taxa belonging to sect. *Adonanthe* in the gen. *Adonis* in East Asia on the basis of morphological and cytological characters, and the evolutionary change of major diagnostic characters and the validity of the existing taxonomic system were reviewed. *Adonis davidii* has been considered the most primitive species of the 11 treated taxa. However, cladistic analysis indicated that *A. davidii* differentiated since *A. sutchuenensis* branched. Evolutionary tendencies of taxonomic characters were generally orthogenesis. However, a few characters evolved in the reverse direction. Meanwhile, the cladistic analysis did not support the classification system proposed by Wang, who classified sect. *Adonanthe* into four series, as most of these were found to be rather polyphyletic or paraphyletic. The differences between these proposed four series were thought to be attributed to the adaptation of only a few morphological characters that pertained to the leaves shape and the petals color.

Introduction

The genus *Adonis* L. belongs to the family Ranunculaceae and is composed of perennial and annual herbaceous plants that are included in the tribe Adonideae under the subfamily Ranunculoideae (Ren et al 2009). Approximately 26–30 species grow in the northern temperate zone, including in Asia, Europe, and North America, and some annual species are known to be distributed from Southwest Asia to North Africa as well as along the shores of the Mediterranean (Mabberley 1990).

After the initial attempt by Linnaeus (1753), De Candolle (1818) established the classification system, including the genus *Adonis* at the section level in which 10 taxa of the genus were divided into the sect. *Adonia* DC.—an annual species with 5–10 petals, 18–20 stamens, erect styles, and cylindrical or globular aggregated achenes—and the sect. *Consiligo* DC.—a perennial species with 8–15 petals, 25–30 stamens, recurved styles, and globular aggregated achenes. There have been various arguments regarding classification of the sect. *Consiligo* DC. For instance, unlike the sect. *Adonia* DC., this group was subdivided into subsection levels (Bobrov 1937; Poschkurlat 1977; Tamura 1990, 1991), and some taxa were treated as independent genera (e.g. gen. *Adonanthe* Spach) or sections (e.g. sect. *Ancistrocarpium* Spach) (Spach 1839). However, the taxonomy of *Adonis* had previously been inferred primarily from European and Central Asian taxa and did not reflect all of the diversity in the characters of *Adonis*. In that regard, Wang (1994a, 1994b) conducted a morphological study of all *Adonis* taxa and proposed a new classification system, recognizing one genus, two subgenera, six sections, and six series.

The sect. *Adonanthe* W. T. Wang in the subgen. *Adonanthe* is divided into ser. *Amurenses* Poschk., which is characterized by ovate, ovate deltoid, or elliptic shaped leaves, and yellow or white petals; ser. *Coeruleae* Poschk. with oblong- or ovate oblong-shaped leaves, and white or purple petals; ser. *Apenninae* Bobr. ex Poschk. with three-pinnately compound leaves; and ser. *Vernales* Bobr. ex Poschk. with three-pinnatisect palmately compound leaves. Son and Ko (2013) have supported this classification system within the sect. *Adonanthe* based on the morphology of aggregated achenes and the microstructure of the achene surface in the genus *Adonis* L. found in East Asia.

However, most of the aforementioned previous studies regarding the genus *Adonis* L. focused on a classification system based on morphological differences, including those associated with the leaf shape and achene characters, whereas a phylogenetic relationship-based classification system of the genus *Adonis* L. has

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not yet been established. Furthermore, Son et al (2016) mentioned that the nrITS data did not support the classification system proposed by Wang, who classified sect. *Adonanthe* into four series as most of these were found to be either polyphyletic or paraphyletic, and further studies are needed to resolve the phylogenetic relationships among *Adonis* in relation to the evolutionary trends of morphological characters.

In this study, cladistics analysis was performed based on morphological characters for 11 taxa of *Adonis* that are distributed in East Asia. Based on these results, the evolutionary tendency for major characters was verified and the validity of the previously determined taxonomy was revised.

Materials and methods

For cladistic analysis, 13 characters that were determined to have distinct evolutionary tendencies among taxa were divided into plesiomorphic and apomorphic groups, considering the characters important for classification of the gen. *Adonis* (De Candolle 1818; Spach 1839; Falconer 1839; Bobrov 1937; Poschkurlat 1977; Iman et al 1977; Wang 1994a, 1994b; Johansson 1999). Plesiomorphic characters were assigned a value of 0 and apomorphic characters a value of 1, whereas multistate characters were assigned various values for each state. These characters and character states are shown in Table 1. *Adonis nepalensis* Simonov. from sect. *Leiocarpa* W.T. Wang of subgen. *Adonanthe*, which is known as the most primitive species of the genus, was selected as an outgroup because sect. *Adonanthe* taxa are originated from A. *nepalensis* of sect. *Leiocarpa* Wang (1994a, 1994b).

A data matrix for characters and character states was generated using MacClade version 4.08 (Sinauer Associates, Sunderland, MA, USA; Table 2). Phylogenetic analyses of the data matrix were performed using maximum parsimony analysis incorporated in the PAUP* version 4.0b10 software program (Sinauer Associates, Sunderland, MA, USA; Figure 1). Heuristic searches were conducted using the ACCTRAN, MULPARS, and TBR branch swapping options turned on. To examine branch support of the generated phylogenetic tree, a bootstrap value (Felsentein 1985) was calculated by repeating the analysis 1,000 times and applying the same conditions. Additionally, the consistency index, retention index, and rescaled consistency index were calculated (Farris, 1989), and MacClade version 4.08 was used for the optimization of character state distribution.

Table 2. Data matrix for cladistic analysis of the section *Adonanthe* in East Asia.

Taxa	Character												
	1	2	3	4	5	6	7	8	9	10	11	12	13
DAV	0	0	0	0	0	1	0	1	0	1	0	1	0
SUT	0	0	0	0	0	1	0	0	0	1	0	2	0
AMU	1	1	1	0	0	1	1	0	0	1	1	2	0
RAM	1	0	0	0	0	1	1	0	0	1	1	2	1
PSE	1	0	0	0	0	1	0	0	1	1	1	2	0
MUL	1	0	0	0	1	1	0	0	0	1	1	2	0
SHI	1	0	0	0	0	1	0	0	0	1	1	2	0
COE	0	0	0	0	0	0	0	1	0	1	0	2	0
APE	1	0	0	1	1	0	0	0	0	1	1	2	0
BOB	0	0	0	1	0	0	0	0	1	1	0	3	0
TIA	0	0	0	1	1	0	0	0	0	1	0	2	0
NEP	0	0	0	0	0	0	0	0	0	0	0	0	0

AMU = *Adonis amurensis*; APE = *A. apennina*; BOB = *A. bobroviana*; COE = *A. coerulea*; DAV = *A. davidii*; MUL = *A. multiflora*; NEP = *A. nepalensis*; PSE = *A. pseudoamurensis*; RAM = *A. ramosa*; SHI = *A. shikokuensis*; SUT = *A. sutchuenensis*; TIA = *A. tianschanicus*.

Results

Cladistics analyses based on morphological characters were conducted on 11 East Asian taxa (sect. *Adonanthe*) to elucidate the relationships between the taxa, verify validity of the existing taxonomy within the genus, and determine the evolutionary tendency of these characters.

As shown in Figure 1, the ingroup taxa from the East Asian sect. *Adonanthe* formed two clades with a bootstrap value of < 50%. Clade 1 comprised *Adonis sutchuenensis* (SUT) and a clade formed by *A. davidii* (DAV) from ser. *Amurenses* and *A. coerulea* (COE) from ser. *Coeruleae* that received < 50% bootstrap support. Clade 2 comprised *Adonis bobroviana* (BOB), *A. tianschanicus* (TIA), and *A. apennina* (APE) from ser. *Apenninae* and *A. multiflora* (MUL), *A. shikokuensis* (SHI), *A. pseudoamurensis* (PSE), *A. ramosa* (RAM), and *A. amurensis* (AMU) from ser. *Amurenses*. AMU and RAM formed a subclade with a bootstrap value of 64%.

Cladistic analysis of the characters, in particular the presence of trichomes on achenes (Char. 10) and a recurved type of persistent style (Char. 12), indicated that species from the sect. *Adonanthe* diverged from *Adonis nepalensis* (NEP), which is known as the most primitive species of gen. *Adonis*. Clade 1 was shown to have differentiated as stipules (Char. 6) developed at the base of petiole. DAV diverged as petals (Char. 8) transitioned from yellow to white,

Table 1. Morphological characters and their states used in cladistic analysis of the section *Adonanthe* in East Asia.

No.	Characters	Character states*	
		Plesiomorph	Apomorph
1	Rhizome shape	Long & deflected, long & vertical (0)	Short (1)
2	Types of stem branching	Branched (0)	Unbranched (1)
3	Timing of leaf development	Coetaneous (0)	Precocious (1)
4	Petiole	Petiolate (0)	Sessile (1)
5	Shapes of final lobules	Ovate, narrowly ovate, lanceolate, narrowly lanceolate (0)	Linear (1)
6	Stipules	Estipulate (0)	Stipulate (1)
7	Length of sepal to petal	Sepal < petal (0)	Sepal ≥ petal (1)
8	Color of petals	Yellow (0)	White, purple (1)
9	Shapes of aggregated achenes	Globose, subglobose (0)	Ellipsoidal (1)
10	Trichomes on achene	Glabrous (0)	Pubescent (1)
11	Persistent style of achene	Short (0)	Long (1)
12	Recurved types of persistent style	Erect (0)	Erect & recurved at tip (1), recurved at base & straight (2), recurved at base & hooked at tip (3)
13	Chromosome number	$2n = 16$ (0)	$2n = 32$ (1)

* Chromosome number cited from Shlangena (1976), Nishikawa and Ito (1978, 1979), Lavrenko and Serditov (1985), Wang and Liu (1988), Nishikawa (1988, 1989a, 1989b), Yang and Wu (1993), Yang (2001), Nishikawa and Ito (2001).