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Taxonomic study of *Broussonetia* (Moraceae) in Korea

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한국산 닥나무속(*Broussonetia*, 뽕나무과)의 분류학적 연구

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ABSTRACT: Three Korean *Broussonetia* species (Moraceae) were reexamined based on morphological characters. The plants which has been used for making traditional paper Hanji in Korea are considered hybrid species between *B. kazinoki* and *B.* papyrifera, its natural habitat was firstly discovered in Is. Gageo (Jeonnam Province). Thus it is newly described as *B.* × *hanjiana* M. Kim. Its Korean name is changed into Daknamu instead of Kkujidaknamu. Therefore, Korean name for *B. kazinoki* is also changed into Aegidaknamu instead of Daknamu. Dioecious plants of *Broussonetia kazinoki* which were found in Is. Gageo are named as *B. kazinoki* for. *koreana* M. Kim (Gageo-Aegidaknamu).

Keywords: *Broussonetia*, Moraceae, Korean paper mulberry, Hanji

적 요: 한국산 닥나무속 식물의 분류학적 특징을 재검토하였다. 한지를 만드는데 사용해 온 닥나무와 꾸지나무의 교잡종인 꾸지닥나무가 전남 신안군 흑산면 가거도에서 자생하고 있어 새로이 *Broussonetia* × *hanjiana* M. Kim으로 명명하였다. 꾸지닥나무는 그동안 일반인들이 닥나무라고 일컫기 때문에 꾸지닥나무 대신에 닥나무라고 하였다. 따라서 *Broussonetia kazinoki*는 닥나무 대신에 애기닥나무라고 변경하였다. 또한 가거도에서 발견된 자웅이주인 애기닥나무를 가거애기닥나무(*B. kazinoki* for. *koreana* M. Kim)라고 새로이 명명하였다.

주요어: 닥나무, 뽕나무과, 한지

Broussonetia occurs worldwide in temperate, subtropical, and tropical climatic zones (Chung, 2007). This is a small genus in Moraceae, as containing about eight deciduous taxa (Kim et al., 1992). Of them, three taxa, *B. kazinoki, B. kazinoki* × *B. papyrifera* and *B. papyrifera*, have been known to be distributed in Korea (Kim et al., 1992).

Broussonetia is distinguished from the other genera within the family by male catkin with globose or cylindrical shape, female catkin with globose shape, inflexed filaments, connated calyx lobes, 3-nerved leaf veins, toothed leaf-margin, and thornless stems (Zhou and Gilbert, 2003).

Based on a study of pollen morphology on *Broussonetia* (including Section *Allaeanthus*), the genus *Allaeanthus* may be shifted into the genus of *Broussonetia* (Kim and Zavada, 1993). In a morphometric study on Korean *Broussonetia* species, it was found that most individuals known as *B. kazinoki* are a hybrid between *B. kazinoki* x *B. papyrifera* (Kim et al., 1992). This hybrid was firstly recorded by Kim et al. (1992). Matthews(1996) has reviewed about the origin and ethnobotany of *B. papyrifera* in Polynesia.

The natural habitats of *B. kazinoki* x *B. papyrifera,* a hybrid taxon, from Is. Gageo located in the most southwestern part of Korea was discovered. We here described *Broussonetia* × *hanjiana* M. Kim as a new hybrid. Also, we reviewed the Korean names of the species of *Broussonetia* in Korea in order to make a correction that have been controversial among species.

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Materials and methods

Living materials of three species of *Broussonetia* were collected from Is. Gageo, Byeonsan, Mt. Naejang, etc. in Korea. The vouchers were deposited in JNU. Ten diagnostic characters from the twenty individuals of each species studied were measured to test relationships among species (Table 1).

Results

1. Morphological study

Morphological characters of three Korean *Broussonetia* species were compared in Table 2.

Leaf: The leaf of *B.* x *hanjiana* have the intermediate size between *B. papyrifera* and *B. kazinok*. Leaf petiole and stipule size of *B. papyrifera* and *B.* × *hanjiana* are more than 1 cm long, but these of *B. kazinoki* less than 1 cm.

Inflorescence: Male plants of *B. papyrifera* and *B.* × *hanjiana* have cylindrical catkin inflorescence, but *B. kazinoki* have globose heads. Female plants of *B. papyrifera* (1.1-1.3 cm) have larger inflorescence in diameter than those of *B.* × *hanjiana* and *B. kazinoki*.

Flowers: Staminate flowers of three *Broussonetia* species have calyx tube with four lobes. Four filaments of three species are inflexed in bud. Pistillate flowers of three *Broussonetia* species have filiform style with stigmatic hairs.

Fruit: Three *Broussonetia* species is sorosis with globose shape, and its fruits are matured on June to July.

Table 1. Collection data of *Broussonetia kazinoki* × *B. papyrifera* with related taxa.

Scientific name (Korean name)	Date	Locality
Broussonetia papyrifera (꾸지나무)	May 15, 2007	Byunsan (Jeonbuk)
	May 20, 2008	Is. Gageodo (Jeonnam)
B. kazinoki x *B. papyrifera* (꾸지닥나무)	May 14, 2007	Jeonju (Jeonbuk)
	May 15, 2007	Mt. Chirisan (Jeonnam)
	May 20, 2008	Is. Gageodo (Jeonnam)
B. kazinoki (닥나무)	May 14, 2007	Jeonju (Jeonbuk)
	May 14, 2007	Mt. Naejangsan (Jeonbuk)
	May 20, 2008	Is. Gageodo (Jeonnam)

2. Taxonomic study

1) ***Broussonetia papyrifera*** (L.) L'Her. ex Vent. in Tabl. Regne. Veg. 3: 548 (1799). Fig. 1-A, B

Korean name: **Kkujinamu 꾸지나무**
English name: Paper Mulberry

Trees deciduous, dioecious. Twig 0.5-0.7 cm diameter. Leaves simple, alternate; blade ovate 14-16 cm long, 9-11 cm wide; margin coarsely serrate, sometimes 3-5 lobed, more or less scabrous; petiole 3-4 cm long. Stipules ovate, free, 1.6-2.0 cm long, 1.0-1.4 cm wide. Staminate inflorescence axillary, cylindrical, 5-7 cm long, bracts lanceolate, peduncle 0.9-1.4 cm long. Pistillate inflorescences globose heads, 1.1-1.3 cm diameter, bracts clavate, 1.7-2.1 mm long. peduncle 0.4-0.9 cm long. Staminate flowers: calyx tubular, 4 lobes; stamen 4, filaments

Table 2. Morphological characters of *Broussonetia kazinoki* × *B. papyrifera* with its related taxa.

Character		*B. papyrifera*	*B. kazinoki* × *B. papyrifera*	*B. kazinoki*
Habit		Tree	Small tree	Shrub
Twig diameter		0.5-0.7 cm*	0.3-0.5 cm	0.1-0.3 cm
Petiole	length	3-4 cm	1-2 cm	0.5-1.0 cm
Lamina	length	14-16 cm	10-12 cm	7-9 cm
	width	9-11 cm	6-8 cm	3-5 cm
Stipule	length	1.6-2.0 cm	1.1-1.5 cm	0.5-0.7 cm
	width	1.0-1.4 cm	0.5-0.7 cm	0.1-0.3 cm
Inflorescence		Dioecious	Dioecious	Monoecious
Male inflorescence	shape	Cylindrical	Cylindrical	Globose
	length	5-7 cm	2-3 cm	0.7-0.8 cm
Female inflorescence	diameter	1.1-1.3 cm	0.6-0.9 cm	0.2-0.4 cm
Female flower	bracrt length	1.7-2.1 mm	1.1-1.5 mm	0.7-0.9 mm
Fruit	diameter	1.7-2 cm	1.0-1.5 cm	1.0-1.5 cm

* Minimum-maximum

Fig. 1. Korean *Broussonetia* species. A, Male plant of *B. papyrifera*; B, Female plant of *B. papyrifera*; C, *B. kazinoki*; D, Male plant of *B.* x *hanjiana* M. Kim; E, Female plant of *B.* × *hanjiana* M. Kim; F, Male plant of *B. kazinoki* for. *koreana* M. Kim; G, Female plant of *B. kazinoki* for. *koreana* M. Kim. Scale bars = 1 cm.

inflexed in bud. Pistillate flowers: calyx pipelike, ovary ovoid, style filiform with stigmatic hairs, 1.0-1.2 cm long. Fruit orange-red when mature, 1.7-2.0 cm diameter, stalk 0.3-0.4 cm long. Fl. May.

Distribution: Korea, Japan, China, Taiwan, Malaysia, Laos, Myanmar, Thailand, Vietnam

Remark: This plant has often been cultivated in China to use as a material for making traditional paper, Gou shu.

Observed Specimens: **KOREA**: Prov. Jeonnam - Is. Imja, 30 Jun. 2000 *H. Im s.n.* (KH); Is. Gageo, 17 Apr. 2007, *M. Kim 6706* (JNU). Prov. Jeonbuk - Byeonsan, 17 Apr. 2007, *M. Kim 6706* (JNU). Prov. Kyeongbuk - Is. Ulleung, 13 May 2003, *S. Park s.n.* (KH). Prov. Kyeongnam - Changnyeong, Upo wetland, 5 Jun. 2006, *S. Park s.n.* (KH).

2) ***Broussonetia* x *hanjiana*** M. Kim, hybrid nov. Fig. 1-D, E. TYPE: Korea, Province Jeonnam, Is. Gageo, 16 May 2008, *M. Kim 9944* (holotype, JNU).

B. kazinoki x *B. papyrifera* in Coloured Ill. Woody Pl. Japan II. 244-245(1981). nom. nud.

Korean name: **Daknamu** 닥나무, Kkujidaknamu (Kim et al., 1992)

English name: Korean Paper Mulberry

Parvus arbor 6-8 m alta; Folia simplex alternus, lamina ovatae 10-12 cm longa, 6-8 cm lata, petioli 1-2 cm longi, margine serratus, secundariis vulgo 5-6, stipulae ovatus 1.1-1.5 cm longi, 0.5-0.7 cm lata; Flos dioecia, Aprilis-Maium florens; Amenta mascula cylindricus 2-3 cm longi, 0.8-1.0 cm diametro, pedicello 1.5-3.0 cm longi, bracteae linearis, calycis lobi 4, stamina 4, filamentis curvatis 3-4 mm longa, antherae

alba; Amenta feminea globosum 0.6-0.9 cm diametro, pedicello 0.4-0.7 cm longi, bracteae cylindricus 1.1-1.5 mm longi, ovarium dimidio superiore pilosum, styli filiformis 0.8-1.2 cm longi; Fructus rubrae, 1.0-1.5 cm diametro, pedicello 0.5-0.6 cm.

Small trees deciduous, dioecious. Twig 0.3-0.5 cm diameter. Leaves simple, alternate; blade ovate 10-12 cm long, 6-8 cm wide, margin coarsely serrate, sometimes 3-5 lobed, more or less scabrous; petiole 1-2 cm long. Stipules lanceolate, free, 1.1-1.5 cm long, 0.5-0.7 cm wide. Staminate inflorescence axillary, cylindrical, 2-3 cm long, bracts lanceolate, peduncle 1.5-3.0 cm long. Pistillate inflorescences globose heads, 0.6-0.9 cm diameter, bracts clavate, 1.1-1.5 mm long. peduncle 0.4-0.7 cm long. Staminate flowers: calyx tubular, 4 lobes; stamen 4, filaments inflexed in bud. Pistillate flowers: calyx pipelike, ovary ovoid, style filiform with stigmatic hairs, 0.8-1.2 cm long. Fruit orange-red when mature, 1.0-1.5 cm diameter, stalk 0.5-0.7 cm long. Fl. May.

Distribution: Is. Gageo in Korea

Etymology: The specific epithet is derived from Korean traditional paper Hanji.

Habitats: Is. Gageo is located in most southwestern part of Korean Peninsular, and has the most natural vegetation and evergreen broad-leaved forest composing with *Castanopsis cuspidata* var. *sieboldii*, *Quercus acuta*, *Dendropanax morbifera*, *Ilex integra*, *Daphniphyllum macropodum*, etc. The natural habitats of *Broussonetia* x *hanjiana* were discovered at western side in the south part of Is. Gageo. This plants grow with dominant species *Machilus thunbergii* in canopy layer, and in shruberry zone with *Mallotus japonicus*, *Euscaphis japonica*, *Callicarpa japonica*. Also it makes herbaceous zone with dominant species: *Miscanthus sinensis*, *Carex lanceolata*, *Phaenosperma globosa*, and minor elements: *Trachelospermum asiaticum* var. *majus*, *Hedera rhombea*, *Ardisia japonica*, *Kadsura japonica*, *Paederia scandens*, *Rubus hirsutus*, *Ficus nipponica*, etc.

Remark: Without latin description and defining holotype, *B. kazinoki* × *B. papyrifera* was described by Kitamura and Murata at 1981. Thus, the name of *B. kazinoki* x *B. papyrifera* was not validly published under the rules of the International Code of Botanical Nomenclature. Until now this species has been cultivated, and the natural habitats were unknown. but through this study its natural habitats were discovered by the authors from Is. Gageo in Jeonnam, Korea. Thus, the authors newly described the hybrid as a new taxon, *Broussonetia* × *hanjiana* M. Kim. This species has been mostly used for making traditional paper Hanji in Korea. Therefore Its Korean name is changed into Daknamu instead of Kkujidaknamu (Kim et al., 1992).

3) ***Broussonetia kazinoki*** Siebold in Verh. Batav. Genootsch. Kunsten 12: 28 (1830). Fig. 1-C.

B. kazinoki var. *humilis* Uyeki in Woody Pl. 27 (1940). nom. nud.

Korean name: **Aegidaknamu 애기닥나무**, Daknamu (Lee, 1996; Lee, 2003)

English name: Small Paper Mulberry

Shrubs deciduous, monoecious. Twig 0.1-0.3 cm diameter. Leaves simple, alternate; blade ovate 7-9 cm long, 3-5 cm wide; margin coarsely serrate, sometimes 3-5 lobed, more or less scabrous; petiole 0.5-1.0 cm long. Stipules linear-lanceolate, free, 0.5-0.7 cm long, 0.1-0.3 cm wide. Staminate inflorescence axillary, globose, 0.7-0.8 cm diameter, bracts lanceolate, peduncle 0.9-1.0 cm long. Pistillate inflorescences globose heads, 0.2-0.4 cm diameter, bracts clavate, 0.7-0.9 mm long. peduncle 0.4-0.5 cm long. Staminate flowers: calyx tubular, 4 lobes; stamen 4, filaments inflexed in bud. Pistillate flowers: calyx pipelike, ovary ovoid, style filiform with stigmatic hairs, 0.5-0.8 cm long. Fruit orange-red when mature, 1.0-1.5 cm diameter, stalk 0.3-0.4 cm long. Fl. May.

Distribution: Korea, Japan, China

Remark: Until now, this taxon has been recorded in Korean flora as Daknamu (Lee, 1996; Lee, 2003), however this has not used for making Korean traditional paper Hanji. The Korean name of *B.* × *hanjiana* M. Kim is changed into Daknamu instead of Kkujidaknamu. Therefore, Korean name for *B. kazinoki* is also changed into Aegidaknamu instead of Daknamu.

Observed specimens: **KOREA**: Prov. Kangwon - Mt. Seorak, 18 Jun. 2006, *M. Kim 6602-6603* (JNU); - Mt. Taebaek, 20 Jul. 2002, *B. Oh et al. s.n.* (KH). Prov. Chungbuk - Cheongwon, 22 May 2005, *G. Yoo s.n.* (KH). Prov. Chungnam - Mt. Chilkap, 25 Jun. 2005, *H. Im s.n.* (KH); - Mt. Kwangdeok, 7 May 2005, *Y. Kim s.n.* (KH); - Gongju, 20 May 2005, *W. Paek s.n.* (KH); - Is. Anmyeon, 18 May 2006, *H. Choi s.n.* (KH). Prov. Jeonbuk - Mt. Jiri, 29 Jun. 2004, *C. Yoon et al. s.n.* (KH); - Byeonsan, 29 Jun. 2004, *G. Chung s.n.* (KH); - Mt. Deogyu, 11 May 2007, *M. Kim 6702* (JNU); - Mt. Naejang, 14 May 2008, *M. Kim 6703* (JNU). Prov. Jeonnam - Mt. Baegyang, 18 Jun. 2004,

Y. Kim et al. s.n. (KH); - Kwangyang, Mt. Baekun, 3 May 2006, *Y. Cho s.n.* (KH). Prov. Kyeongnam - Keumsan, Is. Namhae, 8 May 2002, *E. Jeon s.n.* (KH); - Sancheong, 20 Jun. 2007, *J. Yang s.n.* (KH)

4) ***B. kazinoki* for. *koreana*** M. Kim for. nov. Fig. 1-F, G. TYPE: Korea, Province Jeonnam, Is. Gageo. 16 May 2008, *M. Kim 9946* (holotype, JNU).

Korean name: **Gageo-Aegidaknamu 가거애기닥나무**
English name: Gageo Paper Mulberry

Forma affinis *B. kazinoki*, sed differt a forma dioecia.
This form look like *B. kazinoki*, but it has a dioecious plants.

Distribution: Is. Gageo in Korea

Remark: *B. kazinoki* for. *koreana* M. Kim having a dioecious plants found in Is. Gageo, is distinguish from the speices of *B. kazinoki* having a monoecious plants.

Key to *Broussonetia* x *hanjiana* and its closely related taxa.

1. Trees or Shrubs.
   2. Plant dioecious. Staminate inflorescence cylindrical. Petiole and stipule more than 1 cm diameter.
      3. Petiole 3-4 cm long. Stipules 1.6-2.0 cm long. Pistilate inflorescence more than 1 cm diameter. Staminate inflorescence 5-7 cm long ..... *B. papyrifera*
      3. Petiole 1-2 cm long. Stipules 1.1-1.5 cm long. Pistilate inflorescence less than 1 cm diameter. Staminate inflorescence 2-3 cm long ..... *B.* x *hanjiana*
   2. Plant monoecious. Staminate inflorescence globose. Petiole and stipule less than 1 cm long .... *B. kazinoki*
1. Climbing woody plants ..... *B. kaempferi*

Discussion

This is a review of the Korean *Broussonetia* species based on morphological features. It was reconfirmed that a hybrid species, *B.* x *hanjiana* M. Kim is originated from the natural hybridization between *B. papyrifera* (L.) L'Her. ex Vent. and *B. kazinoki* Siebold. This hybrid has been used for making Korean traditional paper, Hanji (Kim et al., 1992). *Broussonetia* x *hanjiana* did not show variable forms comparing with those of *Ilex* x *wandoensis* C. F. Miller & M. Kim (Miller and Kim, 2002).

Is. Gageo is located in the most southwestern Korea, and has well preserved natural forests composing with *Castanopsis cuspidata* var. *sieboldii*, *Quercus acuta*, *Dendropanax morbifera*, *Ilex integra*, *Daphniphyllum macropodum*, etc. *Broussonetia* x *hanjiana* grows with a dominant species, *Machilus thunbergii*, in canopy layer, and in the shruberry zone with *Mallotus japonicus*, *Euscaphis japonica*, *Callicarpa japonica* in this island. This species has been cultivated around human habitation, its natural habitats, however, has been unknown till now. This study found that, even though Is. Gageo is a small size, this is the only island having all three Korean species of *Broussonetia*: male and female plants of *B. papyrifera*, male and female plants of *B.* x *hanjiana*, monoecious plants of *B. kazinoki*, dioecious plants of *B. kazinoki* for. *koreana*.

The name of *B. kazinoki* x *B. papyrifera* was not validly published under the rules of the International Code of Botanical Nomenclature. This study found its natural habitats from Is. Gageo in Jeonnam, Korea. Thus, we describe a hybrid, *B.* x *hanjiana* M. Kim of *Broussonetia*, as a new taxon. This species has been used for making traditional paper Hanji in Korea. Its Korean name is also changed into Daknamu instead of Kkujidaknamu (Kim et al., 1992). Female plants of this taxon have been cultivating in most region of Japan including Kyoto for making traditional paper, Kozo-shi. Because *B. kazinoki* has not cultivated for making Korean traditional papers Hanji (Lee, 1996; Lee, 2003). its name should be changed into Aegidaknamu instead of Daknamu.

Some plants of *B. kazinoki* found in Is. Gageodo is named as *B. kazinoki* for. *koreana* M. Kim, because these has the same morphological features as those of *B. kazinoki* except for the feature of sexual organ, dioecious. This female plant is cultivating in some region of Japan for making traditional paper, Kozo-shi.

Although all Korean *Broussonetia* species (Moraceae) has been reviewed based on morphological characters in this study, we believe that diverse approaches including molecular systematics using DNA sequences are required to get a better taxonomic understanding of them.

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