Taiwania, **52**(1): 70-83, 2007

Morphological Comparisons of Taiwan Native Wild Tea Plant (*Camellia sinensis* (L.) O. Kuntze forma *formosensis* Kitamura) and Two Closely Related Taxa Using Numerical Methods

Mong-Huai Su[1], Chih-Hua Tsou[2] and Chang-Fu Hsieh[1,3]

(Manuscript received 30 August, 2006; accepted 22 December, 2006)

ABSTRACT: *Camellia sinensis* (L.) O. Kuntze forma *formosensis* Kitamura is generally referred to as the tea plant growing naturally in mid-elevation mountains of Taiwan. Several taxonomic treatments have been published for this plant in the past, but some contradictory results have been obtained. To assess the taxonomic position of the wild tea plant and explore its relationship with two other closely related taxa, *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*, 16 vegetative and 11 floral characters were examined on 165 OTUs. The data were analyzed using cluster analysis and nonlinear principal components analysis. All cluster phenograms consistently separated the native wild tea plant from two other related taxa. Conversely, pronounced admixture between *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* was present. The nonlinear principal components analysis indicated that the surface features of buds and ovaries are two diagnostic characters. Based on the present study, it is proposed that the Taiwan native wild tea plant might deserve recognition as a distinct species.

KEY WORDS: ***Camellia sinensis*** **forma** ***formosensis*****, Native wild tea plant, Taiwan, Numerical taxonomy.**

INTRODUCTION

The native wild tea plant, *Camellia sinensis* (L.) O. Kuntze forma *formosensis* Kitamura, is generally referred to the tea plant growing naturally in the broad-leaved forests at mid-elevations of the Central Mountain Range (CMR) of Taiwan (Wu et al., 1970; Lai et al., 2001). According to collection data from herbaria, it is widely distributed at elevations from 900 to 1800 m in the central, southern and eastern regions of Taiwan, including Nantou, Chiayi, Kaohsiung, Pingtung and Taitung County (Fig. 1). The native wild tea plant in Taiwan was first described in 1717 during the Ching Dynasty. In 1724 a political officer, Su-Jien Huang, mentioned it again in his report to Taiwan. Therefore the native wild tea plant has been known to exist in Taiwan for nearly 300 years.

Tea is one of the most popular beverages in the world. Taxonomically, economic tea plants belong to the genus *Camellia* of family Theaceae. There are two main varieties of tea plants: *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* (Masters) Kitamura (Kitamura, 1950; Sealy, 1958; Ming, 2000). The former is usually processed for green teas (un/hemi-fermented teas), while the latter is for black teas (fully fermented teas). In Taiwan, tea plants are also important crops and have been cultivated for over 200 years. Nevertheless, the cultivated tea plants (*C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*) were imported, and have nothing to do with that native wild tea plant (Hasimoto, 1967; Lai et al., 2001). During the Japanese Colonized Period, the government sought to popularize and encourage the cultivation of the native wild tea plants, but for some reasons it had never been done (Shih, 1995). As a result of the 50-year-long effort, a new cultivar of black tea, “TTES No. 18” or "Red Jade", was finally released by the Tea Research and Extension Station and extended to the farmers in 1999. The “TTES No. 18” is just an artificial hybrid between *C. sinensis* var. *assamica* (maternal) and *C. sinensis* f. *formosensis* (paternal). This tea smells like natural cinnamon and fresh mint and is quite popular among consumers.

Ancient people in the Mt. Alishan area of central Taiwan called the native wild tea plant "Shuen-Cha" which means teas from celestial beings. The folk name is still used today by their descendants. In

1. Institute of Ecology and Evolutionary Biology, National Taiwan University, 1, Sec. 4, Roosevelt Rd., Taipei 106, Taiwan.
2. Institute of Plant and Microbial Biology, Academia Sinica, 128, Sec. 2, Academia Rd., Taipei 115, Taiwan.
3. Corresponding author. Email: tnl@ntu.edu.tw

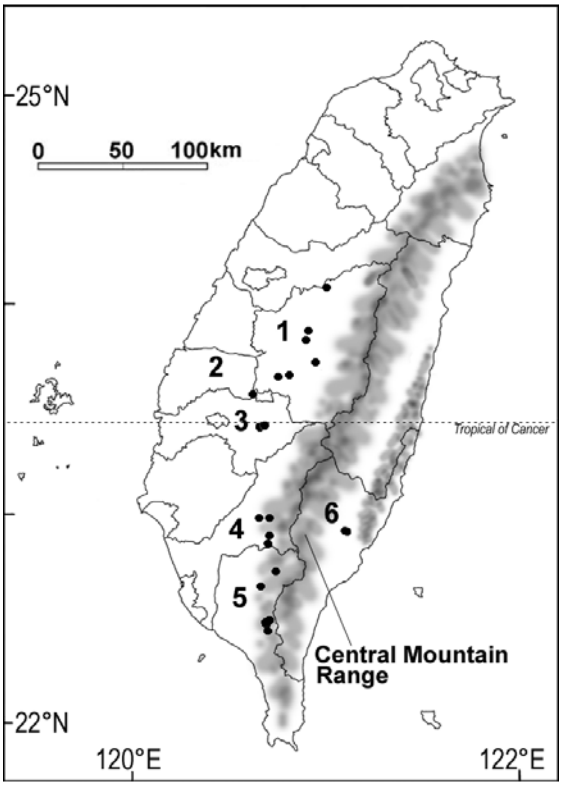

Fig. 1. Distribution map of *C. sinensis* f. *formosensis* based on authors' samples and materials from TAI, TAIF and PPI herbaria. 1: Nantou County. 2: Yunlin County. 3: Chiayi County. 4: Kaohsiung County. 5: Pingtung County. 6: Taitung County.

several reports on tea improvements, the native wild tea plant was named as 'San-Cha' (means teas from mountains) to be distinguished from the imported tea plants (Shih, 1995; Li and Chang, 2003).

Botanical nomenclatures of the native wild tea plant are somewhat complicated. Here we try to clarify it in brief. For its affinity to *C. sinensis* var. *assamica*, Masamune and Suzuki proposed *Thea assamica* Masters var. *formosensis* Masamune et Suzuki for the first time (Masamune, 1936). However, Masamune didn't publish the name validly, because there was no description provided. The correct name first published for this plant should be *Thea formosensis* Masamune et Suzuki (Suzuki, 1937). Later, this taxon was transferred as a forma under *C. sinensis* (Kitamura, 1950) and named as *C. sinensis* f. *formosensis*. In the following four decades, however, this name has been consistently neglected in all studies concerning the taxonomy of *Camellia* (Keng, 1950; Liu and Lu, 1967; Li, 1976; Ying, 1995) until the publication of *Flora of Taiwan, second edition*, in which Hsieh et al. (1996) followed Kitamura's treatment. Ming (2000) also mentioned the same name, but he treated it as a synonym of *C. sinensis*. Although Suzuki (1937) had pointed that native wild tea plant was "*Thea assamica* affinis, sed foliis glabris" and Kitamura (1950) described that the forma was unique by 'Foliis majoribus angustioribus atroviridibus crassioribus', taxonomic uncertainties of this wild tea plant still remain. There had been several attempts to study *C. sinensis* f. *formosensis* based on numerical methods (Wu et al., 1970, 1972; Shih et al., 1972; Hu, 2004), however, all these studies aimed at exploring the variation among populations of *C. sinensis* f. *formosensis*, rather than solving the fundamental taxonomic problems.

In the present study, the morphological variation among *C. sinensis* f. *formosensis* and its two related taxa, *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* is summarized by applying multivariate numerical approaches. The aim is to detect infraspecific boundaries, to identify reliable distinguishing characters. A sound knowledge of taxonomy is a prerequisite for the success of any germplasm conservation program of the wild tea plant of Taiwan.

MATERIALS AND METHODS

Materials

In total, 165 specimens were selected for morphological study (Table 1). Sources of the specimens used in this investigation were deposited in the Herbarium of National Taiwan University (TAI), Herbarium of Taiwan Forest Research Institute (TAIF), Prof. Tzen-Yuh Chiang's Laboratory at the National Cheng Kung University (NCKU), and supplemented by the authors' own collection. Scientific names given on the specimen labels and annotated labels were tentatively used. Among 165 specimens, 72 were identified as *C. sinensis* var. *sinensis*, 41 as *C. sinensis* var. *assamica* and 52 as *C. sinensis* f. *formosensis*. Materials of *C. sinensis* f. *formosensis* were collected from all natural habitats we have known so far. Both *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* are not native to Taiwan. In order to explore the variation of the two closely related taxa, several collections from China were made. Meanwhile, specimens from the Tea Research and Extension Station, which represented tea plants from India, Sri Lanka, Thailand and China, were included.

Character measurement

In this study, each collection was designated as an operational taxonomic unit (OTU). Specimen duplicates were treated as one OTU. Characters were

Table 1. List of voucher specimens included in the present study. Codes are comprised of an abbreviated scientific name, followed by a dash, and then the collection site with a serial number. Codes with an asterisk are the specimens collected from the germplasm banks of the Tea Research and Extension Station. TAI: Herbarium of National Taiwan University; TAIF: Herbarium of Taiwan Forest Research Institute; NCKU: Prof. Tzen-Yuh Chiang's Laboratory at National Cheng Kung University.

Name	Collector with collection number	Site	Date	Herbarium	Code
var. *assamica*	M. H. Su 669	Taiwan, Taipei Co. (Burma type)	2005/10/6	Authors	A-BU1*
	K. S. Wang 5007	China, Yunan Prov. Elv. 1781m	2004/12/1	NCKU	A-CN1
	K. S. Wang 5010	China, Yunan Prov. Elv. 970m	2004/12/1	NCKU	A-CN2
	K. S. Wang 5016	China, Yunan Prov.	2004/12/1	NCKU	A-CN3
	K. S. Wang 5017	China, Yunan Prov.	2004/12/1	NCKU	A-CN4
	K. S. Wang 5019	China, Yunan Prov.	2004/12/1	NCKU	A-CN5
	K. S. Wang 5021	China, Yunan Prov.	2004/12/2	NCKU	A-CN6
	K. S. Wang 5024	China, Yunan Prov.	2004/12/2	NCKU	A-CN7
	K. S. Wang 5026	China, Yunan Prov.	2004/12/2	NCKU	A-CN8
	K. S. Wang 5033	China, Yunan Prov.	2004/12/2	NCKU	A-CN9
	K. S. Wang 5034	China, Yunan Prov. Elv. 1200m.	2004/12/3	NCKU	A-CN10
	K. S. Wang 5035	China, Yunan Prov. Elv. 1200m.	2004/12/3	NCKU	A-CN11
	K. S. Wang 5036	China, Yunan Prov. Elv. 1200m.	2004/12/3	NCKU	A-CN12
	K. S. Wang 5041	China, Yunan Prov. Elv. 1900m.	2004/12/3	NCKU	A-CN13
	K. S. Wang 5042	China, Yunan Prov. Elv. 1900m.	2004/12/3	NCKU	A-CN14
	K. S. Wang 5052	China, Yunan Prov. Elv. 1950m.	2004/12/4	NCKU	A-CN15
	K. S. Wang 5053	China, Yunan Prov.	2004/12/4	NCKU	A-CN16
	K. S. Wang 5054	China, Yunan Prov. Elv. 1470m.	2004/12/4	NCKU	A-CN17
	K. S. Wang 5058	China, Yunan Prov. Elv. 1300m.	2004/12/4	NCKU	A-CN18
	K. S. Wang 5066	China, Yunan Prov. Elv. 1020m.	2004/12/4	NCKU	A-CN19
	K. S. Wang 5072	China, Yunan Prov. Elv. 1400m.	2004/12/5	NCKU	A-CN20
	K. S. Wang 5076	China, Yunan Prov. Elv. 1380m.	2004/12/5	NCKU	A-CN21
	K. S. Wang 5079	China, Yunan Prov. Elv. 1000m.	2004/12/5	NCKU	A-CN22
	K. S. Wang 5084	China, Yunan Prov. Elv. 900m.	2004/12/5	NCKU	A-CN23
	K. S. Wang 5091	China, Yunan Prov. Elv. 900m.	2004/12/5	NCKU	A-CN24
	M. H. Su 670	Taiwan, Taipei Co. (Assam type)	2005/10/6	Authors	A-IN1*
	M. H. Su 667	Taiwan, Taipei Co. (Manipur type)	2005/10/6	Authors	A-IN2*
	M. H. Su 685	Taiwan, Nantou Co. (Sri Lanka type)	2005/11/15	Authors	A-SR1*
	M. H. Su 610	Taiwan, Nantou Co. Elv. 1000m.	2005/2/1	Authors	A-NT1
	M. H. Su 609	Taiwan, Nantou Co. Elv. 1000m.	2005/2/1	Authors	A-NT2
	M. H. Su 608	Taiwan, Nantou Co. Elv. 1000m.	2005/2/1	Authors	A-NT3
	M. T. Kao *s. n.*	Taiwan, Nantou Co.	1955/2/12	TAI	A-NT4
	S. Hibino & S. Suzuki *s. n.*	Taiwan, Nantou Co.	1926/7/17	TAI	A-NT5
	H. Keng, T. S. Liu & M. T. Kao *s. n.*	Taiwan, Nantou Co.	1955/7/20	TAI	A-NT6
	S. Y. Lu 18521	Taiwan, Nantou Co. Elv. 400m.	1986/3/2	TAIF	A-NT7
	S. Y. Lu 18291	Taiwan, Nantou Co. Elv. 700m.	1986/2/7	TAIF	A-NT8
	T. S. Liu & H. Keng 2853	Taiwan, Taitung Co.	1955/8/10	TAI	A-TT1
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	A-TY1
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	A-TY2
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	A-TY3
	M. H. Su 684	Taiwan, Taipei Co. (Thailand type)	2005/11/15	Authors	A-TH1*
var. *sinensis*	C. H. Tsou 2117	China, Fujian Prov. Elv. 500-1200m.	2004/5/12	Authors	S-CN1
	C. H. Tsou et al. 1957	China, Guangdong Prov.	2004/8/6	Authors	S-CN2
	M. S. An 3357	China, Guizhou Prov. Elv. 920m.	2003/5/26	TAIF	S-CN3
	K. F. Wang 1-0560	China, Guizhou Prov. Elv. 650m.	2003/7/15	TAIF	S-CN4
	J. H. Hu 282	China, Hunan Prov. Elv. 500m.	2001/8/19	TAIF	S-CN5
	J. H. Hu 242	China, Hunan Prov. Elv. 880m.	2002/6/2	TAIF	S-CN6
	T. M. Taing 00748	China, Jiangxi Prov. 180m.	2000/10/22	TAIF	S-CN7
	Z. Chen 09769	China, Sichuan Prov. Elv. 810m	1996/10/5	TAIF	S-CN8
	T. Makino *s. n.*	Japan, Tokyo City.	1910/10	TAIF	S-JP1
	M. H. Su 640	Taiwan, Chiayi Co. Elv. 1100m.	2005/9/12	Authors	S-CY1
	M. H. Su 644	Taiwan, Chiayi Co. Elv. 800m.	2005/9/13	Authors	S-CY2
	M. H. Su 95	Taiwan, Hsinchu Co.	2003/5/8	Authors	S-HC1
	Y. Shimada *s. n.*	Taiwan, Hsinchu Co.	1913/11/15	TAIF	S-HC2
	A. T. Hsieh *s. n.*	Taiwan, Miaoli Co.	1929/12/14	TAIF	S-ML1
	S. W. Chung 7520	Taiwan, Nantou Co. Elv. 700-800m.	2004/6/10	TAIF	S-NT1
	S. P. Chien *s. n.*	Taiwan, Taipei City	1984/6/18	TAI	S-TP1
	C. S. Kuoh 2952	Taiwan, Taipei City	1971/11/23	TAI	S-TP2
	C. M. Kuo 5457	Taiwan, Taipei City	1974/7/6	TAI	S-TP3

Table 1. Continued.

Name	Collector with collection number	Site	Date	Herbarium	Code
var. *sinensis*	H. Simizu 418	Taiwan, Taipei City	1934/12/15	TAI	S-TP4
	Y. Yamamoto *s. n.*	Taiwan, Taipei City	1930/11/29-30	TAI	S-TP5
	C. M. Kuo 9279	Taiwan, Taipei City	1978/1/2	TAI	S-TP6
	S. Suzuki *s. n.*	Taiwan, Taipei City	1931/8/2	TAI	S-TP7
	G. Masamune 1534	Taiwan, Taipei City	1931/11/24	TAI	S-TP8
	S. Sasaki *s. n.*	Taiwan, Taipei City	1922/10/15	TAI	S-TP9
	S. Suzuki *s. n.*	Taiwan, Taipei City	1932/12/18	TAI	S-TP10
	S. Suzuki *s. n.*	Taiwan, Taipei City	1929/11/30	TAI	S-TP11
	S. Sasaki *s. n.*	Taiwan, Taipei City	1916/5	TAI	S-TP12
	S. Sasaki *s. n.*	Taiwan, Taipei City	1925/12/9	TAI	S-TP13
	K. C. Yang 1162	Taiwan, Taipei City	1982/11/28	TAI	S-TP14
	C. C. Chou 41	Taiwan, Taipei City.	1984/6/18	TAI	S-TP15
	Y. Yamamoto *s. n.*	Taiwan, Taipei City.	1938/2/27	TAI	S-TP16
	N. Y. Gu *s. n.*	Taiwan, Taipei City.	1936/10/28	TAI	S-TP17
	B. L. Shie *s. n.*	Taiwan, Taipei City. Elv. 850m.	1985/7/16	TAIF	S-TP18
	H. L. Chiang 423	Taiwan, Taipei City.	1997/6/15	TAIF	S-TP19
	S. Sasaki *s. n.*	Taiwan, Taipei City.	1923/2	TAIF	S-TP20
	S. Sasaki *s. n.*	Taiwan, Taipei City.	1927/10	TAIF	S-TP21
	K. C. Yang et al. 5265	Taiwan, Taipei City.	1996/12/31	TAIF	S-TP22
	S. Y. Lu 3335	Taiwan, Taipei City. Elv. 600m.	1975/11/19	TAIF	S-TP23
	M. H. Su 197	Taiwan, Taipei Co. Elv. 500m.	2003/5/13	Authors	S-TP24
	C. C. Hsu 5211	Taiwan, Taipei Co.	1968/12/27	TAI	S-TP25
	S. F. Huang K188	Taiwan, Taipei Co.	1987/7/31	TAI	S-TP26
	W. S. Tang *s. n.*	Taiwan, Taipei Co.	1984/12/1	TAI	S-TP27
	S.Suzuki *s. n.*	Taiwan, Taipei Co.	1924/11/2	TAI	S-TP28
	C. M. Kuo 6689A	Taiwan, Taipei Co.	1978/8/29	TAI	S-TP29
	T. C. Huang 9756	Taiwan, Taipei Co.	1982/8/1	TAI	S-TP30
	S. Suzuki *s. n.*	Taiwan, Taipei Co.	1923/10/21	TAI	S-TP31
	T. C. Huang, T. I. Yang & K. C. Yang 1737	Taiwan, Taipei Co.	1985/10/18	TAI	S-TP32
	C. M. Kuo 5549	Taiwan, Taipei Co.	1974/7/28	TAI	S-TP33
	T. C. Huang & K. C. Yang 1924	Taiwan, Taipei Co.	1985/11/22	TAI	S-TP34
	J. H. Lii 236	Taiwan, Taipei Co. Elv. 200-400m.	2000/8/31	TAIF	S-TP35
	S. Y. Lu 12906	Taiwan, Taipei Co.	1983/9/15	TAIF	S-TP36
	H. M. H. Chang	Taiwan, Taipei Co. Elv. 400m.	1999/10/12	TAIF	S-TP37
	H. L. Chiang 218	Taiwan, Taipei Co. Elv. 500m.	1996/10/6	TAIF	S-TP38
	W. F. Ho 314	Taiwan, Taipei Co.	1996/6/13	TAIF	S-TP39
	Y. H. Chang 4810	Taiwan, Taipei Co. Elv. 200-500m.	2001/10/11	TAIF	S-TP40
	S. C. Wu et al. *s. n.*	Taiwan, Taipei Co. Elv. 350-500m.	1996/8/22	TAIF	S-TP41
	W. F. Ho	Taiwan, Taipei Co.	1997/6/6	TAIF	S-TP42
	C. M. Chen *s. n.*	Taiwan, Taipei Co.	2002/9/23	TAIF	S-TP43
	Y. H. Chang 4865	Taiwan, Taipei Co.	2001/10/18	TAIF	S-TP44
	W. F. Ho 126	Taiwan, Taipei Co.	1996/5/16	TAIF	S-TP45
	M. F. Loa & K. C. Yang 80	Taiwan, Taipei Co. Elv. 180-200m.	1996/10/5	TAIF	S-TP46
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	S-TY1
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	S-TY2
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	S-TY3
	Y.Y.-K.K. *s. n.*	Taiwan, Taoyuan Co.	1937/3/2	TAI	S-TY4
	Y. Shimada *s. n.*	Taiwan, Taoyuan Co.	1913/11/20	TAIF	S-TY5
	Y. Shimada *s. n.*	Taiwan, Taoyuan Co.	1913/11/20	TAIF	S-TY6
	Y. Shimada *s. n.*	Taiwan, Taoyuan Co.	1913/11/20	TAIF	S-TY7
	Y. Shimada *s. n.*	Taiwan, Taoyuan Co.	1913/11/20	TAIF	S-TY8
	Y. Shimada *s. n.*	Taiwan, Taoyuan Co.	1913/11/20	TAIF	S-TY9
	Y. Shimada *s. n.*	Taiwan, Taoyuan Co.	1913/11/15	TAIF	S-TY10
	Unknown (TAIF no. 31474)	Unknown	Unknown	TAIF	S-NN1
f. *formosensis*	M. H. Su 642	Taiwan, Chiayi Co. Elv. 1300m.	2005/9/12	Authors	F-CY1
	C. I. Hu *s. n.*	Taiwan, Chiayi Co.	2004/6	Authors	F-CY2*
	H. Yamada *s. n.*	Taiwan, Chiayi Co.	-	TAIF	F-CY3
	Tang et al. 606	Taiwan, Kaohsiung Co. Elv. 1800m.	2005/1/2	Authors	F-KH1
	C. I. Hu *s. n.*	Taiwan, Kaohsiung Co.	2004/6	Authors	F-KH2*
	C. C. Chuang & M. T. Kao 3369	Taiwan, Kaohsiung Co. Elv. 1350m.	1965/2/8	TAI	F-KH3

Table 1. Continued.

Name	Collector with collection number	Site	Date	Herbarium	Code
f. *formosensis*	T. Kiang & M. T. Kao KT439	Taiwan, Kaohsiung Co.	1971/5/12	TAI	F-KH4
	M. T. Kao 7448	Taiwan, Kaohsiung Co.	1968/12/10	TAI	F-KH5
	T. C. Huang 4952	Taiwan, Kaohsiung Co.	1968/12/10	TAI	F-KH6
	A. Tanimura *s. n.*	Taiwan, Kaohsiung Co.	1935/1/12	TAI	F-KH7
	S. Sasaki *s. n.*	Taiwan, Kaohsiung Co.	1936/3/8	TAI	F-NN8
	S. Y. Lu 18256	Taiwan, Kaohsiung Co. Elv. 1150m.	1986/1/30	TAIF	F-KH9
	S. Y. Lu 18664	Taiwan, Kaohsiung Co. Elv. 1500m.	1986/3/11	TAIF	F-KH10
	Y. H. Lai 83	Taiwan, Kaohsiung Co. Elv. 750-800m.	1996/12/2	TAIF	F-KH11
	C. P. Lin *s. n.*	Taiwan, Kaohsiung Co. Elv. 650m.	2004/5/25	TAIF	F-KH12
	C. H. Tsou 2134	Taiwan, Nantou Co. Elv. 1200m.	2005/3/30	Authors	F-NT1
	C. H. Tsou 2132	Taiwan, Nantou Co. Elv. 1200m.	2005/3/30	Authors	F-NT2
	C. H. Tsou 2137	Taiwan, Nantou Co. Elv. 1200m.	2005/3/30	Authors	F-NT3
	C. H. Tsou 2139	Taiwan, Nantou Co. Elv. 1200m.	2005/3/30	Authors	F-NT4
	M. H. Su 687	Taiwan, Nantou Co.	2005/11/15	Authors	F-NT5
	M. H. Su 683	Taiwan, Nantou Co.	2005/11/15	Authors	F-NT6
	M. Hasimoto *s. n.*	Taiwan, Nantou Co.	1966/1/13	TAI	F-NT7
	S. Sasaki *s. n.*	Taiwan, Nantou Co.	1935/11/8	TAI	F-NT8
	S. Taniguchi *s. n.*	Taiwan, Nantou Co.	1931/7/12	TAI	F-NT9
	S. Suzuki 3245	Taiwan, Nantou Co.	1935/11/8	TAI	F-NT10
	S. Sasaki *s. n.*	Taiwan, Nantou Co.	1935/11/8	TAI	F-NT11
	M. Hasimoto *s. n.*	Taiwan, Nantou Co.	1966/1/16	TAI	F-NT12
	S. Sasaki *s. n.*	Taiwan, Nantou Co.	1935/10/8	TAI	F-NT13
	M. T. Kao 6668	Taiwan, Nantou Co.	1966/4/23	TAI	F-NT14
	B. J. Wang 15069	Taiwan, Nantou Co.	1988/12/25	TAIF	F-NT15
	S. Sasaki *s. n.*	Taiwan, Nantou Co.	1922/11/30	TAIF	F-NT16
	M. H. Su 575	Taiwan, Pingtung Co. Elv. 1400m.	2004/4/14	Authors	F-PT1
	M. H. Su 269	Taiwan, Pingtung Co.	2003/9/20	Authors	F-PT2
	M. H. Su 270	Taiwan, Pingtung Co. Elv. 1300m.	2003/9/20	Authors	F-PT3
	M. H. Su 497	Taiwan, Pingtung Co. Elv. 1200m.	2004/1/24	Authors	F-PT4
	M. H. Su 498	Taiwan, Pingtung Co. Elv. 1200m.	2004/1/24	Authors	F-PT5
	M. H. Su 646	Taiwan, Pingtung Co. Elv. 1100m.	2005/9/27	Authors	F-PT6
	M. H. Su 645	Taiwan, Pingtung Co. Elv. 1100m.	2005/9/27	Authors	F-PT7
	M. H. Su 544	Taiwan, Pingtung Co. Elv. 1100m.	2004/3/10	Authors	F-PT8
	M. H. Su 545	Taiwan, Pingtung Co. Elv. 1100m.	2004/3/10	Authors	F-PT9
	E. Matuda *s. n.*	Taiwan, Pingtung Co.	1919/7/11	TAI	F-PT10
	E. Matuda	Taiwan, Pingtung Co.	1912/11/7	TAI	F-PT11
	K. C. Yang et al. 4583	Taiwan, Pingtung Co. Elv. 850m.	1995/12/2	TAIF	F-PT12
	K. C. Yang et al. 4527	Taiwan, Pingtung Co. Elv. 750-1100m.	1995/12/3	TAIF	F-PT13
	S. W. Chung 7090	Taiwan, Pingtung Co. Elv. 800-1000m.	2004/5/29	TAIF	F-PT14
	M. H. Su 659	Taiwan, Taitung Co. Elv. 1000m.	2005/9/28	Authors	F-TT1
	M. H. Su 661	Taiwan, Taitung Co. Elv. 1100m.	2005/9/28	Authors	F-TT2
	M. H. Su 660	Taiwan, Taitung Co. Elv. 1100m.	2005/9/28	Authors	F-TT3
	M. H. Su 655	Taiwan, Taitung Co. Elv. 1100m.	2005/9/28	Authors	F-TT4
	M. T. Kao 6612	Taiwan, Taoyuan Co.	1966/1/11	TAI	F-TY1
	K. Mori 1901	Taiwan, Yunlin Co.	1906/11/5	TAIF	F-YL1
	Tanimura *s. n.*	Unknown	1935/1/12	TAI	F-NN1

chosen with respect to variation among taxa mentioned in literature and based on personal observations on specimens. Finally, a total of 35 characters were scored, including 17 vegetative and 18 floral characters (Table 2). For each specimen, five mature, healthy-look leaves were scored and averaged. The measurement on floral characters was averaged from one to three flowers, depending on the condition of the specimens. We also measured the angles between the midrib and one major lateral vein at two different positions (Fig. 2), because the usual curved lateral veins cannot be expressed by a single value (often measured at the base in most studies).

Upon further examination, it was found that one vegetative and seven floral characters were constant (not informative) and should be eliminated from the following analyses. Finally, 27 (16 vegetative and 11 floral) characters were selected. Since not all specimens were in the flowering stage, the data for the numerical analyses were divided into three

Table 2. List of morphological characters examined for multivariate analyses. The asterisk (*) denotes constant characters that are excluded from the data analysis. The angles measured between midrib and lateral vein are shown in Fig. 2.

Character	Data type
Vegetative Characters	
Bud pubescence	Multi-state
Young branchlet pubescence	Binary
Leaf length	Quantitative
Leaf width	Quantitative
Leaf thickness (dry specimen)	Quantitative
Leaf shape	Multi-state
Leaf apex shape	Multi-state
Leaf base shape	Multi-state
Leaf serration density (count / 4 cm)	Quantitative
Leaf pubescence on adaxial surface*	Binary
Leaf pubescence on abaxial surface	Binary
Abaxial midrib pubescence	Binary
Pairs of lateral veins	Quantitative
Lateral vein angle at base (Fig. 2a)	Quantitative
Lateral vein angle at middle (Fig. 2b)	Quantitative
Petiole length	Quantitative
Petiole pubescence	Binary
Floral characters	
Pedicel length	Quantitative
Pedicel pubescence*	Binary
Petal number per flower	Quantitative
Petal length	Quantitative
Petal width	Quantitative
Petal pubescence*	Multi-state
Sepal number per flower*	Quantitative
Sepal length	Quantitative
Sepal width	Quantitative
Sepal pubescence	Multi-state
Filament length	Quantitative
Filament pubescence*	Binary
Style length	Quantitative
Style number per flower*	Quantitative
Style pubescence*	Binary
Stigma number*	Quantitative
Ovary pubescence	Binary
Flower number per cluster	Quantitative

categories: (1) only vegetative characters (165 OTUs × 16 characters); (2) only floral characters (62 OTUs × 11 characters); and (3) all characters (62 OTUs × 27 characters).

Cluster analysis

Similarity matrices were generated using the coefficient proposed by Gower (1971). Gower's similarity coefficient (GSC) was designed to deal with mixed type of characters, and was thus widely used (Schultze-Motel and Meyer, 1981; Zaharof, 1988; Cheng, 1990; Ward, 1993; Gugerli, 1997; St-Laurent et al., 2000; Muvaffak et al., 2001; Binns et al., 2002; Bayly et al., 2003; Mckenzie et al., 2004). This similarity matrix was then used to perform a cluster analysis using the Unweighted Pair Grouping Method Based on Arithmetic Averages (UPGMA) (Sokal and Michener, 1958) with the software MVSP v3.01 (Kovach Computing Service, 1999).

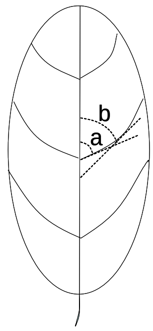

Fig. 2. Scheme of a leaf showing the angles (a) formed between the midrib and a lateral vein, and (b) created by the midrib and the interception of the tangent to the middle portion of a lateral vein.

Nonlinear principal component analysis

To further explore the pattern of variation in measured characters and to find those characters which are decisive to distinguish taxa, a nonlinear principal components analysis (NLPCA, de Leeuw, 1982) was undertaken. Similar to principal components analysis, NLPCA can be used for transforming attributes of a dataset into a new set of uncorrelated attributes (principal components), while still retaining as much of the variability of the dataset as possible. It can handle variables of different types (nominal, ordinal and numerical) simultaneously, and deal with nonlinear relationships between variables. NLPCA is performed by the program CATPCA implemented in the software SPSS v13.0 (SPSS Inc.). In addition, Cronbach's Alpha (Cronbach, 1951) was calculated for each of the components extracted. If Alpha value of a specific component is high, it would be interpreted as indicating that the component has a strong one-dimensional structure, or, the dimension is reliable to account for the total variance. Generally, an Alpha value of 0.70 or greater is considered to be reliable (Bland and Altman, 1997).

RESULTS

Vegetative characters

The UPGMA phenogram based on vegetative characters showed two discrete clusters (Fig. 3), namely Group I-1 (GSC = 0.62) and Group I-2 (GSC = 0.67). Group I-1 was composed entirely of *C. sinensis* f. *formosensis* from central and southern Taiwan. Within this cluster, there did not appear to be any regional patterns. Group I-2, however, contained all the samples of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*, with *C. sinensis* f. *formosensis* from eastern Taiwan. Despite of that, samples of eastern *C. sinensis* f. *formosensis* formed a consistent subgroup (Group I-2-1; GSC = 0.87) within Group I-2. In contrast, all samples of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* overlapped extensively and together they formed a large subgroup (Group I-2-2; GSC = 0.71).

Fig. 3. Phenogram of UPGMA cluster analysis based on vegetative characters. The coefficient was defined as the Gower's similarity coefficient.

The results of NLPCA on the vegetative characters are presented in Table 3. The first three components accounted for 65.3 % of the total variance in the dataset. The first component alone accounted for 43.2% of the total variance and was far more important than other components. The first component with a Cronbach's alpha value of 0.91 was the only one considered to be reliable. The component loadings correspond to the correlation coefficients between characters and the derived components. Characters with high loadings were bud pubescence, young branchlet pubescence, abaxial midrib pubescence and petiole pubescence (over 0.9), followed by leaf length, leaf apex shape and pairs of lateral veins (over 0.7). The plot by the first two components (Fig. 4) shows a similar grouping with the cluster analysis. However, the eastern samples of *C. sinensis* f. *formosensis* were placed onto the intermediate positions in NLPCA. It didn't group these eastern samples with *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* absolutely.

Table 3. Loadings of the 16 vegetative characters on the first three components from NLPCA. Eigenvalues, percentage of variance explained and cumulated, and Cronbach's Alpha are given for each component.

Character	Component		
	1	2	3
Bud pubescence	-0.93	0.29	-0.05
Young branchlet pubescence	0.91	-0.32	0.03
Leaf length	-0.77	-0.55	-0.09
Leaf width	-0.55	-0.71	0.17
Leaf thickness	0.13	-0.10	0.25
Leaf shape	-0.33	0.10	0.47
Leaf apex shape	-0.74	-0.02	-0.26
Leaf base shape	0.14	-0.02	0.60
Leaf serration density	0.34	0.73	0.03
Leaf pubescence on abaxial surface	0.67	-0.23	0.36
Abaxial midrib pubescence	0.90	-0.32	0.06
Pairs of lateral veins	-0.79	-0.27	0.13
Lateral vein angle at base	-0.39	0.16	0.64
Lateral vein angle at middle	-0.64	0.13	0.41
Petiole length	-0.50	-0.35	-0.18
Petiole pubescence	0.91	-0.30	0.04
Eigenvalue	6.90	2.03	1.51
Variance explained (%)	43.20	12.70	9.40
Variance cumulative (%)	43.20	55.90	65.30
Cronbach's Alpha	0.91	0.54	0.36

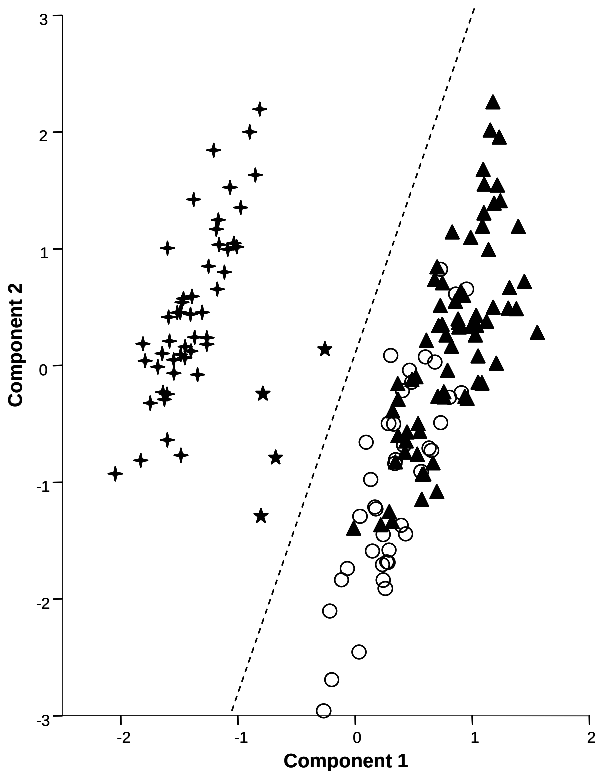

Fig. 4. Ordination plot of NLPCA based on vegetative characters. ✦: central and southern *C. sinensis* f. *formosensis*. ★: eastern *C. sinensis* f. *formosensis*. ○: *C. sinensis* var. *assamica*. ▲: *C. sinensis* var. *sinensis*.

Floral characters

Cluster analysis of OTUs based on floral characters revealed two main groups (i.e. Group II-1 and Group II-2; Fig. 5), similar to the result obtained based on vegetative characters (Fig. 3). However, the members within each cluster were different. The OTUs of *C. sinensis* f. *formosensis* from eastern Taiwan, previously clustered within Group I-2, are now located amongst Group II-1. Consequently, Group II-1 encompassed all samples of *C. sinensis* f. *formosensis*, while Group II-2 consisted of a mix of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*. A further subdivision of the two main groups into geographical or taxonomic subgroups could not be made.

The results of NLPCA on floral characters are shown in Table 4. The first three principal components accounted for 39.1%, 13.2% and 10.8% of the total variance, respectively. Only the first principal component was meaningful (Cronbach's alpha = 0.84) for grouping samples discretely. Characters with high loadings on the first principal component were petal length, petal width and ovary pubescence (over 0.8), followed by sepal width and style length (over 0.7). *C. sinensis* f. *formosensis* also can be separated by a line on the plot of the first two components (Fig. 6), a result just the same with that of the cluster analysis.

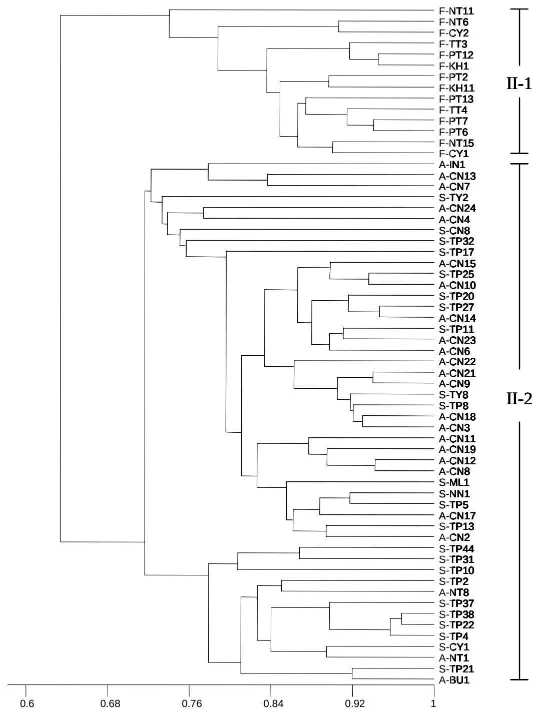

Fig. 5. Phenogram of UPGMA cluster analysis based on floral characters. The coefficient was defined as the Gower's similarity coefficient.

Table 4. Loadings of the 11 floral characters on the first three components from NLPCA. Eigenvalues, percentage of variance explained and cumulated, and Cronbach's Alpha are given for each component.

Character	Component		
	1	2	3
Pedicel length	0.66	0.23	-0.34
Petal number per flower	0.39	0.15	0.61
Petal length	0.85	-0.16	0.02
Petal width	0.80	-0.16	0.19
Sepal length	0.58	0.31	-0.09
Sepal width	0.71	0.50	-0.05
Sepal pubescence	0.14	-0.54	0.65
Filament length	0.47	-0.42	-0.23
Style length	0.78	-0.19	-0.14
Ovary pubescence	0.80	0.05	0.19
Flower number per cluster	-0.15	0.70	0.39
Eigenvalue	4.30	1.46	1.19
Variance explained (%)	39.10	13.20	10.80
Variance cumulative (%)	39.10	52.30	63.10
Cronbach's Alpha	0.84	0.35	0.18

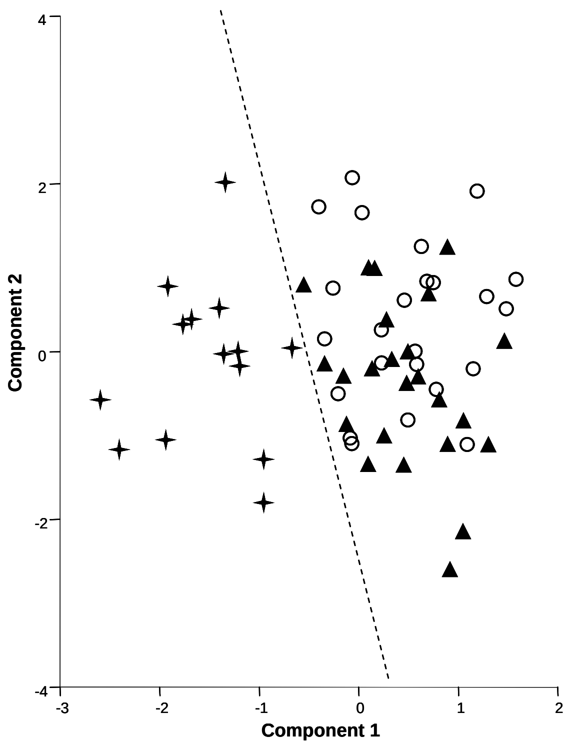

Fig. 6. Ordination plot of NLPCA based on floral characters. ✦: *C. sinensis* f. *formosensis*. ○: *C. sinensis* var. *assamica*. ▲: *C. sinensis* var. *sinensis*.

All characters

Cluster analysis of all the floral and vegetative characters produced a phenogram with two groups of OTUs (Group III-1 and Group III-2, Fig. 7) that corresponded to the separation based on floral characters. OTUs of *C. sinensis* f. *formosensis* were

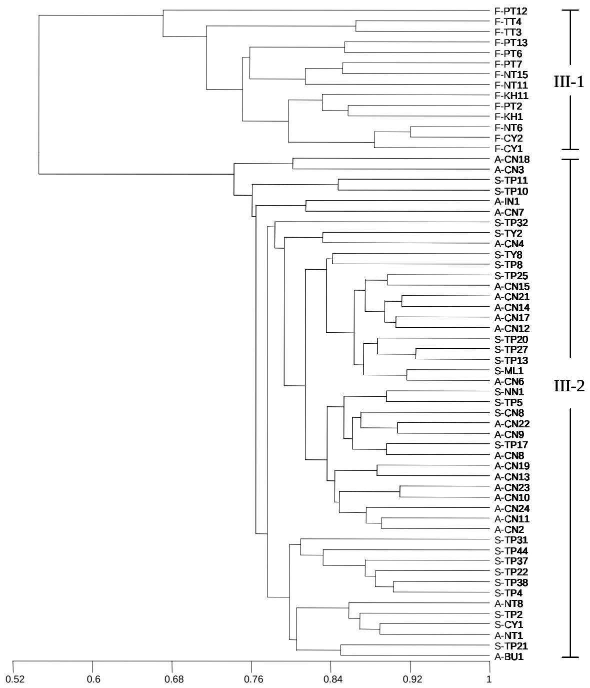

Fig. 7. Phenogram of UPGMA cluster analysis based on vegetative and floral characters. The coefficient was defined as the Gower's similarity coefficient.

contained entirely within Group III-1, while *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* were dispersed throughout Group III-2.

The NLPCA character loadings, percentage, and variance explained and cumulated for the first three components are given in Table 5. The first component accounted for 36.8% of the total variance observed, and was highly interpretable (Cronbach's alpha = 0.93). It had high contributing component loadings from bud pubescence, young branchlet pubescence, abaxial midrib pubescence, petiole pubescence and ovary pubescence (over 0.88), and leaf length, leaf apex shape, leaf pubescence on abaxial surface, pairs of lateral veins, petal length, petal width and sepal width (over 0.65). Figure 8 shows that the first principal component effectively separates *C. sinensis* f. *formosensis* from *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*. The second component was just on the level of reliability (Cronbach's alpha = 0.71), with negative loading on leaf width, and positive loading on leaf serration density. The results of this study also showed that characters with high component loadings based on all characters were in agreement with those only based on vegetative or floral characters. The plot of the first two components based on all characters (Fig. 8) shows a clearer separation of *C. sinensis* f. *formosensis* from the other related taxa than only on vegetative or floral characters. It suggests that both vegetative and floral characters should be taken into consideration for distinguishing these taxa.

Table 5. Loadings of the 27 vegatative and floral characters on the first three components from NLPCA. Eigenvalues, percentage of variance explained and cumulated, and Cronbach's Alpha are given for each component.

Character	Component		
	1	2	3
Bud pubescence	-0.95	0.19	0.10
Young branchlet pubescence	0.89	-0.21	-0.15
Leaf length	-0.67	-0.62	-0.08
Leaf width	-0.46	-0.81	0.05
Leaf thickness	0.15	-0.18	-0.38
Leaf shape	-0.55	-0.05	-0.13
Leaf apex shape	-0.65	-0.03	-0.06
Leaf base shape	-0.26	-0.16	-0.20
Leaf serration density	0.26	0.71	0.11
Leaf pubescence on abaxial surface	0.73	-0.40	0.03
Abaxial midrib pubescence	0.89	-0.21	-0.15
Pairs of lateral veins	-0.70	-0.49	0.07
Lateral vein angle at base	-0.25	-0.25	0.69
Lateral vein angle at middle	-0.52	-0.19	0.63
Petiole length	-0.48	-0.35	-0.32
Petiole pubescence	0.89	-0.21	-0.15
Pedicel length	0.59	-0.23	0.30
Petal number per flower	0.27	-0.52	-0.02
Petal length	0.75	0.00	0.24
Petal width	0.71	-0.09	0.17
Sepal length	0.49	-0.20	0.25
Sepal width	0.66	-0.29	0.03
Sepal pubescence	-0.20	-0.11	0.49
Filament length	0.29	-0.02	0.51
Style length	0.63	0.01	0.24
Ovary pubescence	0.91	-0.17	-0.14
Flower number per cluster	-0.21	-0.49	-0.15
Eigenvalue	9.95	3.11	2.12
Variance explained (%)	36.80	11.50	7.90
Variance cumulative (%)	36.80	48.30	56.20
Cronbach's Alpha	0.93	0.71	0.55

DISCUSSION

Morphological distinctiveness of *C. sinensis* f. *formosensis*

The results of clustering analyses based on the floral (Fig. 5) and all characters (Fig. 7) showed almost a similar clustering pattern. In both phenograms all *C. sinensis* f. *formosensis* samples were grouped into a single cluster and clearly separated from *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*. Although the phenogram based on vegetative characters alone showed an inconsistency position of *C. sinensis* f. *formosensis* from eastern Taiwan (Group I-2, Fig. 3), the plot of the first two components based on vegetative characters indicated the eastern *C. sinensis* f. *formosensis* is intermediate morphologically rather

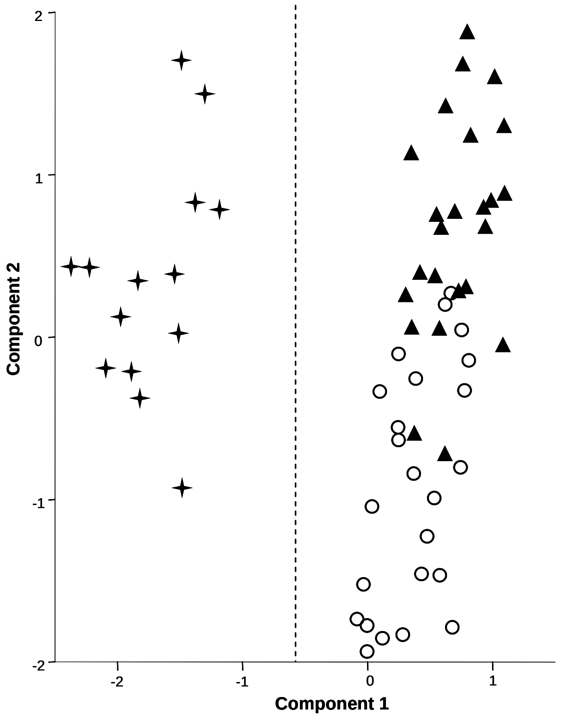

Fig. 8. Ordination plot of NLPCA based on vegetative and floral characters. ✦: *C. sinensis* f. *formosensis*. ○: *C. sinensis* var. *assamica*. ▲: *C. sinensis* var. *sinensis*.

than closed to the other two taxa (Fig. 4). Taken together, the present study has shown that clear morphological differences existed between C. *sinensis* f. *formosensis* and two other closely related taxa, and it seems not proper to treat it as the same as *C. sinensis* var. *sinensis* as considered by Ming (2000).

The present results show that reproductive organs provide more informative characters for the classification of tea plant than do vegetative structures. This is in close agreement with that previously reported by Banerjee (1992a). In general, reproductive characters have been considered more useful than vegetative features in plant systematics (Stuessy, 1990).

In both cluster analysis and NLPCA, the currently recognized varieties *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* integrated considerably. Economic tea plants are heterogeneous with many overlapping morphological attributes. Most vegetative characters show a continuous variation and a high degree of plasticity, and hence, cannot be separated into discrete groups to identify various taxa (Banerjee, 1992a). For the improvement of tea quality, it did happen that artificial hybridizations on the two taxa in the history (Banerjee, 1992b). In this study, some materials of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* were collected from the wild in China or the germplasm banks, which were thought to be genetically independent. Other materials were sourced from tea gardens which might possibly be hybrids. These hybrids have intermediate characteristics that may confuse their identification. However, the individuals of *C. sinensis* f. *formosensis* formed a clearly defined group, and were never embedded in the group of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*.

Hu (2004) used 15 leaf characters measured on 132 tea germplasms to evaluate inter-taxa variation among *C. sinensis* var. *sinensis*, *C. sinensis* var. *assamica* and *C. sinensis* f. *formosensis*. In the scatterplot of PCA (Hu, 2004, Fig. 4), all individuals of the three taxa showed two distinct groups. Individuals from *C. sinensis* f. *formosensis* were dispersed throughout both groups. This is incongruent with present study. Two reasons may explain these inconsistent results. First, characters considered as diagnostic in the present study such as bud pubescence, young branchlet pubescence, abaxial midrib pubescence and petiole pubescence were not used by Hu. Only 7 out of the 15 characters (Hu, 2004, Table 10) adopted by Hu were used in the present study, but these characters were not significantly different among taxa in both studies. Second, Hu transformed nominal characters to ordinal variables for PCA analysis, and this would produce results different from those derived from NLPCA with the same characters. A comparison between PCA and NLPCA showed that the NLPCA would gain more loadings and led to a better performance than PCA (Ellis et al., 2006).

Taxonomic rank of *C. sinensis* f. *formosensis*

As mentioned before, there has been controversial regarding the appropriate taxonomic rank of *C. sinensis* f. *formosensis*. Current study showed that *C. sinensis* f. *formosensis* could be clearly discerned from *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* in both cluster analysis and NLPCA. In contrast, extensive overlap was found between *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*, even though these two varieties have long been recognized as distinct species (Chang, 1984) or infraspecies (Kitamura, 1950; Sealy, 1958; Ming, 2000). Therefore, it is quite probable that *C. sinensis* f. *formosensis* might deserve the species rank. Further work, perhaps including molecular approaches, may be necessary to resolve these taxonomic questions.

Morphological identification of *C. sinensis* f. *formosensis*

Based on the results of morphological study and NLPCA, several characters were found useful to distinguish among these tea plants (Table 6). The surface features of buds and ovaries with the highest component loadings clearly separated *C. sinensis* f. *formosensis* from *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* by the first principal component. The buds of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* are densely covered with silver-yellowish hairs, whereas those of *C. sinensis* f. *formosensis* are glabrous or partly covered with sparse hairs. The surface features of buds have been previously used to identify *C. sinensis* f. *formosensis* by Suzuki (1937) and Kitamura (1950). The surface of ovaries was also a reliable and stable character. Ovaries of *C. sinensis* f. *formosensis* are glabrous while those of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* are pubescent. The importance of reproductive characters in the taxonomy of *Camellia* has been previously reported (Hsieh et al., 1996).

Based on herbarium specimens, the flowering time of *C. sinensis* f. *formosensis* extends from September to January. After that period identification can only be based on vegetative characters. In most cases, young branches, abaxial midribs and petioles of *C. sinensis* f. *formosensis* are glabrous, while those of *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* are hairy. There are, however, some inconsistencies that do not fit with the above delineation. The samples of *C. sinensis* f. *formosensis* from eastern Taiwan share some characteristics with *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* such as sparsely hairy young branches, abaxial midribs and petioles.

Other characters with higher component loadings included leaf pubescence on abaxial surface, pairs of lateral veins and petal size. However, variation of these characters was continuous with some degree of overlap across taxa and was not considered to be the most taxonomically discriminating. The angles between midrib and lateral veins have been considered by local technical personals to be useful characters for distinguishing. They feel the angles were usually wider in *C. sinensis* f. *formosensis*. However, component loadings of these characters were low, indicating that the use of these characters to discriminate among taxa is not reliable.

Phytogeography of *C. sinensis* f. *formosensis*

The remarkable floristic similarity between Taiwan and southeastern China has long been recognized (Li, 1957; Hsieh, 2003). Migrations between Taiwan and mainland China were facilitated by the presence of the Taiwan Strait land bridge that had connected Taiwan and mainland China several times during the glacial ages. The close morphological affinity between *C. sinensis* f. *formosensis* and *C. sinensis* implied that this forma may originated in mainland China.

There was a marked difference in distribution patterns between the western and eastern populations of *C. sinensis* f. *formosensis* (Fig. 1). *C. sinensis* f. *formosensis* is distributed almost continuously throughout the western side of Taiwan, while there is only one population on the southeastern flank of the Central Mountain Range. The eastern population was likely the result of post-glacial range expansion of the populations in western Taiwan. The little separation between the western and eastern populations of *C. sinensis* f. *formosensis* in vegetation characters indicated that the vegetative characters of this plant displayed a stronger response to environmental variables than did floral characters. Future research should explore different approaches, including the use of different molecular markers, to establish the post-glacial migration patterns of the Taiwan wild tea plant and determine its origin.

Table 6. Useful characters to distinguish *C. sinensis* f. *formosensis* from *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*. An asterisk (*) denotes characters that are (nearly) decisive.

Character	*C. sinensis* f. *formosensis*	*C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica*
Bud pubescence*	glabrous or sparsely covered with hairs at margins	densely covered with silver-yellowish hairs
Young branchlet pubescence	glabrous except for eastern populations	nearly all hairy
Abaxial midrib pubescence	glabrous except for eastern populations	nearly all hairy
Petiole pubescence	glabrous except for eastern populations	nearly all hairy
Leaf pubescence on abaxial surface	glabrous	mostly hairy
Pairs of lateral veins	8-14, mostly > 10	5-12, mostly < 10
Ovary pubescence *	glabrous	pubescent
Petal length	0.7-1.3 cm	1.1-2.1 cm
Petal width	0.6-1.1 cm	0.7-2.0 cm

ACKNOWLEDGEMENTS

We greatly appreciate TAI, TAIF, PPI, Tea Research and Extension Station and Prof. Tzen-Yuh Chiang for their support and permission to examine the related specimens. Financial support was provided by the National Science Council of the Republic of China (NSC-95-2422-H-002-002).

LITERATURE CITED

Banerjee, B. 1992a. Botanical classification of tea. In: Willson, K. C. and M. N. Clifford (eds.), Tea: Cultivation to consumption. Chapman & Hall, London, UK. pp. 25-51.

Banerjee, B. 1992b. Selection and breeding of tea. In: Willson, K. C. and M. N. Clifford (eds.), Tea: Cultivation to consumption. Chapman & Hall, London, UK. pp. 53-86.

Bayly, M. J., A. V. Kellow, P. J. D. Lange, K. A. Mitchell, K. R. Markham, P. J. Garnock-Jones and P. J. Brownsey. 2003. Geographic variation in morphology and flavonoid chemistry in *Hebe pubescens* and *H. bollonsii* (Scrophulariaceae), including a new infraspecific classification for *H. pubescens*. N. Z. J. Bot. **41**: 23-53.

Binns, S. E., B. R. Baum and J. T. Arnason. 2002. A taxonomic revision of *Echinacea* (Asteraceae: Heliantheae). Syst. Bot. **27**: 610-632.

Bland, J. M. and D. G. Altman. 1997. Statistics notes: Cronbach's alpha. Brit. Med. J. **314**: 572.

Chang, H.-T. 1984. A revision on the tea resource plants. Acta Sci. Nat. Univ. Sunyatseni **23**: 1-12.

Cheng, W.-T. 1990. Populational studies on Formosan *Lilium* (Liliaceae) I. A cluster analysis of variants in *L. longiflorum* Thunb. Taiwania **35**: 198-205.

Chou, C.-S. 1717. Chu-Lo-Hsien-Chi. The 56th year of the Kangxi Emperor, Ching Dynasty. Reprinted in 1962 by Bank of Taiwan, Taipei, Taiwan. p. 286.

Cronbach, L. J. 1951. Coefficient alpha and the internal structure of tests. Psychometrika **16**: 297-334.

de Leeuw, J. 1982. Nonlinear principal components analysis. In: Caussinus, H., P. Ettinger, and R. Tomassone (eds.), COMPSTAT Proceedings in Computational Statistics, Physica Verlag, Vienna, Austria. pp. 77-89.

Ellis, R. N., P. M. Kroonenberg, B. D. Harch and K. E. Basford. 2006. Non-linear principal components analysis: an alternative method for finding patterns in environmental data. Environmetrics **17**: 1-11.

Gower, J. C. 1971. A general coefficient of similarity and some of its properties. Biometrics **27**: 857-871.

Gugerli, F. 1997. Hybridization of *Saxifraga oppositifolia* and *S. biflora* (Saxifragaceae) in a mixed alpine population. Plant Syst. Evol. **207**: 255-272.

Hasimoto, M. 1967. Studies on the wild tea plants from Taiwan. Sci. Rep. Fac. Agric. Meijo Univ. **4**: 17-20.

Hsieh, C.-F. 2003. Composition, endemism and phytogeographical affinities of the Taiwan Flora. In: Huang, T.-C. et al. (eds.), Flora of Taiwan, 2nd ed. **6**: 1-14. Editorial Committee, Dept. Bot., NTU, Taipei, Taiwan.

Hsieh, C.-F., L.-K. Ling and K.-C. Yang. 1996. *Camellia*, Theaceae. In: Huang, T.-C. et al. (eds.), Flora of Taiwan, 2nd ed. **2**: 667-674. Editorial Committee, Dept. Bot., NTU, Taipei, Taiwan.

Hu, C.-Y. 2004. Studies on the variations in leaf characters and DNA sequences of tea germplasm in Taiwan. M. S. Thesis. National Taiwan University, Taipei, Taiwan. 146pp.

Huang, S.-J. 1724. Report on the Topography, Culture, Society, Resources, Inhabitants and History of Taiwan (Taihai Shichalu). The 61st year of the Kangxi Emperor, Ching Dynasty. Reprinted in 1957 by Bank of Taiwan, Taipei, Taiwan. p. 62.

Keng, H. 1950. The Theaceae of Taiwan. Taiwania **1**: 223-268.

Kitamura, S. 1950. On tea and camellias. Acta Phytotaxon. Geobot. **14**: 56-63.

Lai, J.-A., W.-C. Yang and J.-Y. Hsiao. 2001. An assessment of genetic relationships in cultivated tea clones and native wild tea in Taiwan using RAPD and ISSR markers. Bot. Bull. Acad. Sin. **42**: 93-100.

Li, H.-L. 1957. The genetic affinities of the Formosan flora. Proceedings of the Eighth Pacific Science Congress **4**: 189-195.

Li, H.-L. 1976. Theaceae. In: Li, H.-L. et al. (eds.), Flora of Taiwan **2**: 592-619. Epoch Publ. Co., Taipei, Taiwan.

Li, T.-C. and C.-K. Chang. 2003. Tea germplasm resources in Taiwan. Tea Research and Extension Station, Taoyuan, Taiwan. p. 173.

Liu, T.-S. and F.-Y. Lu. 1967. Studies in the Taiwan Theaceae based on the morphological characters of leaves. Tech. Bull. Exp. For. Nat. Taiwan Univ. **52**: 1-55.

Masamune, G. 1936. Short Flora of Formosa. The Editorial Department of "Kudo", Taihoku (Taipei), Taiwan. p. 140.

Mckenzie, R. J., J. M. Ward, J. D. Lovis and I. Breitwieser. 2004. Morphological evidence for natural intergeneric hybridization in the New Zealand Gnaphalieae (Compositae): *Anaphalioides bellidioides* × *Ewartia sinclairii*. Bot. J. Linn. Soc. **145**: 59-75.

Ming, T.-L. 2000. Monograph of the Genus *Camellia*. Yunnan Science and Technology Press, Kunming, China. pp. 128-134.

Muvaffak, A., M. Dogan and C. C. Bilgin. 2001. A numerical taxonomic study of the genus *Acantholimon* Boiss. (Plumbaginaceae) in Ankara Province (Turkey). Isr. J. Plant Sci. **49**: 298-300.

Schultze-Motel, J. and D. Meyer. 1981. Numerical taxonomic studies in the genera *Triticum* L. and *Pisum* L. Genet. Resour. Crop Evol. **29**: 241-250.

Sealy, J. 1958. A revision of the genus *Camellia*. Royal Horticultural Society, London, UK. 239pp.

Shih, C., Y.-S. Chen, S.-K. Yang, C.-Y. Shih and T.-L. Liau. 1972. Investigation of the wild tea plants in Nantou, Taiwan. Taiwan Agric. Quart. **8**: 193-201.

Shih, Y.-S. 1995. Translated documents of tea agricultural articles during Japanese Colonized Period. Tea Research and Extension Station, Taoyuan, Taiwan. 521pp.

Sokal, R. R. and C. D. Michener. 1958. A Statistical Method for Evaluating Systematic Relationships. Univ. Kansas Sci. Bull. **38**: 1409-1438.

St-Laurent, L., B. R. Baum, K. Akpagana and J. T. Arnason. 2000. A numerical taxonomic study of *Trema* (Ulmaceae) from Togo, West Africa. Syst. Bot. **25**: 399-413.

Stuessy, T. F. 1990. Plant Taxonomy: The Systematic Evaluation of Comparative Data. Columbia University Press, New York, USA. 514pp.

Suzuki, S. 1937. Taiwan Zyumoku Benran, Taihoku (Taipei), Taiwan. p. 262.

Ward, J. M. 1993. Systematics of New Zealand Inuleae (Compositae - Asteraceae) - 2. A numerical phenetic study of *Raoulia* in relation to allied genera. N. Z. J. Bot. **31**: 29-42.

Wu, C.-T., J.-H. Fong and J.-M. Tsay. 1972. Observation on the morphological characters of the wild tea plants on Mt. Meiyuan of Taiwan (II). Taiwan Agric. Quart. **8**: 133-159.

Wu, C.-T., Y.-H. Chia, J.-H. Fong and J.-M. Tsay. 1970. Observation on the morphological characters of the wild tea plants on Mei-yuan Mountain of Taiwan. Taiwan Agric. Quart. **6**: 1-10.

Ying, S.-S. 1995. Systematic study on Theaceae of Taiwan. Memoirs of the College of Agriculture, National Taiwan University **35**: 131-170.

Zaharof, E. 1988. A phenetic study of *Fritillaria* (Liliaceae) in Greece. Plant Syst. Evol. **161**: 23-34.

利用數值分類方法比較臺灣野生茶與兩近緣分類群之形態特徵關係

蘇夢淮[1]、鄒稚華[2]、謝長富[1,3]

(收搞日期：2006 年 8 月 30 日；接受日期：2006 年 12 月 22 日)

摘　　要

臺灣野生茶 (*Camellia sinensis* f. *formosensis*) 乃泛指自生於臺灣中海拔山區的茶類植物，臺灣植物誌將其中名稱為臺灣山茶。在分類史上，臺灣野生茶曾經被處理成數個不同分類階層的歸屬。為了提供分類學者一個更客觀的看法，我們利用數值分類方法中的群聚分析 (cluster analysis) 與非線性主成份分析 (nonlinear principal component analysis)，計算了 165 份標本中的 16 個營養及 11 個花部特徵的測量值，並依據分析結果來探究臺灣野生茶與關係密切的茶 (*C. sinensis* var. *sinensis*) 和阿薩姆茶 (*C. sinensis* var. *assamica*) 的區別。將營養及花部特徵獨立或合併進行群聚分析的結果幾乎一致地指出臺灣野生茶在形態特徵上的獨立性。相反地，茶與阿薩姆茶的形態差異卻無法被解析出來。非線性主成份分析則顯現休眠芽與子房的毛被狀態是區分臺灣野生茶以及茶與阿薩姆茶的最有效特徵。參照目前分類學家對茶與阿薩姆茶這兩群植物的分類處理，我們建議臺灣野生茶應該被處理成種的階層會比較恰當。

關鍵詞：野生茶、臺灣山茶、臺灣、數值分類。

1. 國立臺灣大學生態學與演化生物學研究所，106台北市羅斯福路4段1號，臺灣。
2. 中央研究院植物暨微生物學研究所，115 台北市研究院路 2 段 128 號，臺灣。
3. 通信作者。Email: tnl@ntu.edu.tw