Morphological classification and phylogenetic evolution of section *Thea* in the genus *Camellia.*

Liang Chen[1,3], Fulian Yu[1], Luhuan Lou[2], Qiqing Tong[3]
1: *Tea Research Institute, Chinese Academy of Agricultural Sciences*, 1 Yunqi Rd., Hangzhou, Zhejiang 310008, P. R. China; 2: *Zhejiang Forestry College*, Lin'an, Zhejiang 311300, P. R. China; 3: *Tea Science Dept., Zhejiang University*, 268 Kaixuan Rd., Hangzhou, Zhejiang 310029, P. R. China

Summary

The current situations of morphological, cytological and chemical classification of section *Thea* in genus *Camellia* were briefly introduced, the rationality and shortcoming of main classification systems were reviewed. A new phylogenetic classification system of section *Thea* was put forward on the basis of the previous scientists' work and the authors' long term of research of tea germplasms and comprehensive investigation of tea plants in the original center areas. It was mainly based on the locule number of ovary, the splitting number of style and the pubescence of ovary. Meanwhile, the thickness of pericarp, sepal exterior pubescence, the size of flower and the other morphological characteristics, such as tree habit, branch and leaf characteristics were considered. The section *Thea* was revised into 5 species and 2 varieties: *Camellia tachangensis* F. C. Zhang, *C. crassicolumna* Chang, *C. taliensis* (W. W. Smith) Melchior, *C. gymnogyna* Chang, *C. sinensis* (L.) O. Kuntze, *C. sinensis* var. *assamica* (Masters) Kitamura, *C. sinensis* var. *pubilimba* Chang. An identification key to section *Thea* was given and the morphological characteristic, the geographical distribution and the evolutionary tendency of the species and varieties were in detail described.

Keywords Distribution; Evolution; Genus *Camellia*; Morphological classification; Sect. *Thea*

1 Introduction

Sect. *Thea* (L.) Dyer is a section in the genus *Camellia* L., Theaceae. They are evergreen arbor, semi-arbor or shrub, 1-3 axillary flowers, white color in middle or small size with stalk, 2 or 3(4) bracts fallen off early, 5-7 sepals, 5-13(15) nearly separated petals, 3-4 layers of stamens, 3-5 locules of ovary with or without pubescence, (2) 3-5(7) splittings of style, capsule in flat or circular round shape with central axis, thick or thin pericarp, seed without feather (Chang 1981a, 1981b; Ming 1992). The systematics of section *Thea* has been controversial for many years. The objectives of this paper were to 1) propose a new morphological systematics based the previous achievements of the other scientists and the authors' comprehensive researches and understandings of tea germplasms, 2) have a brief introduction of the characteristics, distribution and evolutionary tendency of section *Thea.*

2 Status quo of classification of section *Thea*

2.1 Morphological classification

Linnaeus established genus *Thea* L. in 1753 based on *Thea sinensis* L. as a type species. Dyer combined genus *Thea* into genus *Camellia* as a section *Thea* (L.) Dyer in 1874. Sealy (1958) revised 5 species and 1 variety in section *Thea.* Since 1980s after wide and systematical investigation of wild tea germplasms in southwestern China, more and more taxa in section *Thea* had been released (Chen, 1996). Chang (1981a, 1981b) classified section *Thea* into 4 series, series *Quinquelocularis* Chang, series *Pentastylae* Chang, series *Gymnogynae* Chang and series *Sinenses* Chang, 17species and 3 varieties. He revised 32 species and 3 varieties (Chang, 1984), later released 5 more species (Tang *et al.*, 1984; Chang, 1990). According to Chang's system, there were 44 species and 3 varieties till 1990 (Chen, 1996). Ming (1992) revised 47 species and 3 varieties in section *Thea* and section *Glaberrima* Chang and recognized 12 species and 6 varieties.

2.2 Chemical, mathematical and cytological, classification

Du *et al.* (1990), based on chemical, morphological and geographical total 65 characteristics using mathematical method, combined 21 species into 2 species and 3 varieties, *C. quinquelocularea* Du et Li with 5-locule, *C. triloculare*a Du et Li with 3-locule, var. *micro-midphyllaea* Du et Li, var. *macrophyllaea* Du et Li and var. *kucha* Du et Li.

Liang *et al.* (1994) investigated the karyotype of 7 species and 1 variety of section *Thea* in Guizhou, China. According to the symmetrical degree of chromosome and karyotype, the species and variety were divided into two groups. One was primitive/symmetrical karyotype with 5-locule of ovary, including series *Quinquelocularis* and series *Pentastylae.* The other was evolutional/anisomerous type with 3-locule of ovary, including series *Gymnogynae* and series *Sinenses* of Chang's system. The results of Du and Liang could generally validate each other.

3 Reviews of the previous classification systems of section *Thea*

3.1 The Chang's system

Chang's system (19811, 1981b, 1984), the most authoritative one and having worldwide influence, mainly based on the differentiation degree, particularly on the locule number, the pubescence of ovary and splitting number of style divided section *Thea* into 4 series, then according to the quantitative characteristics, such as stalk, sepal, petal, pericarp, development of fruit and leaf to subdivide the species and conduct evolutionary tendency analysis. It was an entire and elaborate classification system. However, it depended too much on subjective judgment of the specimens and lacked of objective criteria of species, thus resulted in enormous species.

3.2 The Ming's system

Ming (1992) further examined the specimens and studied the section *Thea*. He found many of them were synonym or misnamed. He combined section *Glaberrima* Chang into section *Thea* and removed *C. pubicosta* Merr. from section *Thea* to section *Corallina* Sealy due to its separate style. He made a large scale of revision and combination, recognized 12 species and 6 varieties. The species borderline of his system was much clearer than Chang's and the rank of series was canceled. The system had a significant advancement on phylogeny of section *Thea*. However, the species were still too much, a lot of them were still of continuous and ambiguous characteristics.

3.3 The Du's and Liang's classification

Du's (1990) and Liang's (1994) groupings based on chemistry and karyotype were consistent with the special morphological characteristics—the locule number of ovary. They paid attentions to the difference of 3- or 5-locule ovary when they conducted classification. However, the distinct difference of ovary pubescence was ignored.

4 Our morphological classification system

Since 1980, the scientists from Tea Research Institute, Chinese Academy of Agricultural Science (TRI, CAAS) have been systematically investigating the wild tea species in the original center area of Yunnan and nearby Guangxi, Guizhou and Sichuan of China. More than 400 specimens from near 50 counties merely in Yunnan were collected. The 17 species and 1 variety released by Chang (1984) and Tang *et al.* (1984) were based on these specimens. Two national tea germplasm repositories were established in 1990 in TRI, CAAS and TRI, Yunnan Academy of Agricultural Sciences (TRI, YAAS). More than 2600 accessions of tea germplasms have been preserved including 24 species and varieties according to Chang's system, over 600 accessions of them have been evaluated using multidiscipline methods (Chen & Yu, unpublished data).

On the basis of prior scientists' achievements and our long-term research and sophisticated understanding of tea germplasms, we proposed a new phylogenetic classification of section *Thea*. It was primarily based on the locule number and pubescence of ovary, splitting number of style, then considered the thickness of pericarp, calyx pubescence, the size of flower and other morphological traits, such as tree habit, branch and leaf. The system adequately took into consideration of the remarkable morphological difference among tea plants, especially in flowers, and also paid attention to the conceptions of taxonomic and biological species. For both convenient to utilization in research and production and easily to distinguish each other, the section *Thea* was revised into 5 species and 2 varieties: *Camellia tachangensis* F. C. Zhang, *C. crassicolumna* Chang, *C. taliensis* (W. W. Smith) Melchior, *C. gymnogyna* Chang, *C. sinensis* (L.) O. Kuntze, *C. sinensis* var. *assamica* (Masters) Kitamura, *C. sinensis* var. *pubilimba* Chang. The wild tea trees usually belonged to the 4 former species; only a small ratio was *C. sinensis*. Cultivated tea plants belonged to *C. sinensis* and its varieties. An identification key to the section *Thea* was as follows.

Key to section *Thea*

1. 5(7)-locule ovary, 5(7)-splitting style.
   2. Ovary without pubescence; leaf, apical bud and young shoot without pubescence ····· 1 *C. tachangensis*
   2. Ovary with pubescence.
      3. Without pubescence except ovary and the interior of sepal; capsule in flat round shape, pericarp 2-3 mm in thickness ····· 2 *C. taliensis*
      3. With or at least ovary, apical bud and style with pubescence; capsule in circular round shape, pericarp 5-7 mm in thickness, with thick central axis ····· 3 *C. crassicolumna*
1. 3(4)-locule ovary, 3(4)-splitting style.
   4. Ovary without pubescence; large flower more than 5 cm in diameter, leather texture leaf ····· 4*C. gymnogyna*
   4. Ovary with pubescence; small flower, soft or light leather texture leaf ····· 5 *C. sinensis*
      5. The exterior of sepal without pubescence, young shoot with or without pubescence.
         6. Thick and fragile, middle or small leaf, less than 11 cm; shrub or semi-arbor ····· 5a *C. sinensis* var. *sinensis*
         6. Large soft leaf, usual over 12 cm; arbor or sub-arbor ····· 5b *C. sinensis* var. *assamica*
      5. The exterior of sepal, young shoot with dense pubescence; thick and leather texture leaf ··· 5c *C. sinensis* var. *pubilimba*

5 Morphological characteristics and geographical distribution of section *Thea*

5.1 *Camellia tachangensis* F. C. Zhang (Zhang, 1980; Chang 1981a, 1981b, 1984; Ming, 1992)

—*C. kwangsiensis* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992), **syn. nov.**; *C. quinquelocularis* Chang (Chang, 1981a, 1981b, 1984); *C. tetracocca* Chang (Chang, 1981a, 1981b, 1984); *C. grandibracteata* Chang et Yu (Chang, 1984), **syn. nov.**; *C. kwangnanica* Chang et Chen (Chang, 1984); *C. remotiserrata* Chang et Wang (Tang *et al.*, 1984; Chang, 1990).

High arbor; young shoot, apical bud and leaf with or without pubescence; leaf in elliptic or oblong shape, leather texture; sepal 5-8mm, large flower, (9) 11-13(15) petals, (4) 5-locule ovary without pubescence, (4) 5-splitting style; capsule in flat or near circular round shape with 3-4 mm middle thick pericarp. It is one of the most primitive species in section *Thea*.

It grows in the evergreen broad-leaved forests at the altitude of 1500-2500 m in eastern, southeastern and western Yunnan, southwestern Guizhou and western Guangxi of China.

5.2 *Camellia taliensis* (W. W. Smith) Melchior (Sealy, 1985; Chang, 1981a, 1981b, 1984; Ming, 1992)

—*C. irrawadiensis* P. K. Barua (Sealy, 1958; Chang, 1981a, 1981b, 1984; Ming, 1992); *C. pentastyla* Chang (Chang, 1981a, 1981b, 1984); *C. changningensis* F. S. Zhang (Zhang *et al.*, 1990; Ming 1992); *C. quinquebracteata* Chang et Ye (Ye, 1987; Ming, 1992,); *C. longlingensis* F. S. Zhang (Zhang *et al.*, 1990; Ming, 1992); *C. taliensis* var. *bangweicha* F. C. Zhang (Zhang, 1994) **syn. nov.**

High arbor; young shoot, apical bud and leaf without pubescence; leaf in elliptic or oblong shape, leather texture; large flower, 10-13 petals, (4) 5-locule ovary with pubescence, (4) 5-splitting style; capsule in flat circular round shape with 2-3 mm thin pericarp. It also is one of the most primitive species in section *Thea*.

It grows in the evergreen broad-leaved forests at the altitude of 1300-2700 m in western, southeastern Yunnan of China and northern Burma.

5.3 *Camellia crassicolumna* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992)

—*C. crispula* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992); *C. atrothea* Chang et Wang (Chang, 1984; Ming, 1992); *C. rotundata* Chang et Yu (Chang, 1984; Ming, 1992); *C. makuanica* Chang et Tang (Chang, 1984; Ming, 1992); *C. haaniensis* Chang et Yu (Chang, 1984; Ming, 1992); *C. multiplex* Chang et Tang (Chang, 1984; Ming, 1992)

High arbor; at least young shoot, apical bud with pubescence; leaf in oblong shape, soft leather texture; thick pedicel, large calyx and flower, 11-13(15) petals, 5-locule ovary with pubescence, 5-splitting style; capsule in circular round shape with big central axis and more than 5 mm thick pericarp. It also is one of the most primitive species in section *Thea*.

It grows in the evergreen broad-leaved forests at the altitude of 1600-2300 m in southeastern, central Yunnan, southwestern Guizhou and western Guangxi of China.

The significant difference between *C. crassicolumna* and *C. taliensis* exists in the former species has pubescence at least on young shoot, apical bud and with thick central axis and thick pericarp.

5.4 *Camellia gymnogyna* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992)

—*C. costata* Hu et Liang (Chang, 1981a, 1981b, 1984; Ming, 1992), **syn. nov.**; *C. yungkiangensis* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992); *C. leptophylla* S. Y. Liang(Chang, 1981a, 1981b, 1984; Ming, 1992), **syn. nov.**; *C. dehungensis* Chang et Chen (Chang, 1981a, 1981b, 1984; Ming, 1992), **syn. nov.**; *C. parvisepaloides* Chang et Wang (Chang,1984; Ming, 1992); *C. manglaensis* Chang et Tang (Tang *et al.*,1984; Ming, 1992); *C. gymnogynoides* Chang et Yu (Tang *et al.*,1984; Chang, 1990; Ming,1992); *C. jinyunshanica* Chang et J. H. Xiong (Chang, 1990; Ming,1992); *C. nanchuanica* Chang et J. H. Xiong (Chang, 1990; Ming,1992)

Arbor or semi-arbor, young shoot and apical bud with or without pubescence; large leaf in oblong shape, leather or soft leather texture; large calyx, 5-8mm and large flower reaching 5 cm in diameter, 7-10 petals, 3 (4)-locule ovary with pubescence, 3 (4)-splitting style; capsule in circular round shape.

It grows in the evergreen broad-leaved or artificial forests at the altitude of 500-2200 m in southeastern, northeastern Yunnan, western Sichuan, northern Guangdong and southern Jiangxi of China.

5.5 *Camellia sinensis* (L.) O. Kuntze (Sealy, 1958; Chang, 1981a, 1981b, 1984; Ming, 1992)

It is widely distributed in the tea growing areas in China, from northern—Mountain Dabieshan to western —Motuo and Bomi in Tibet, from eastern—southeastern seashore to southern—Hainan island, and in more than 50 countries around the world, from N 43 degree to S 22 degree latitude, E 150 degree to W 60 degree longitude. A lot of variations have been created in the long history of cultivation. Generally, arbor, semi-arbor or shrub; large or small leaf with or without pubescence; large or small flower, 5-12 petals, 3-locule ovary with pubescence, 3-splitting style; capsule with different shapes.

5.5.1 var. *sinensis*

—*C. sinensis* var. *waldensae* (S.Y. Hu) Chang (Chang, 1981a, 1981b, 1984); *C. purpurea* Chang et Chen (Chang, 1984; Ming, 1992), **syn. nov.**; *C. arborescens* Chang et Yu (Tang et al., 1984; Chang, 1990; Ming,1992)

It has been cultivated for a long time. Various cultivars of numerous variations in tree height, growth habit, leaf size, flower traits, chemical components, etc. have been bred. However, it is still of basic characteristics: semi-arbor or shrub, young shoot and leaf with or without pubescence, thick and hard leaf in small size, elliptic or oblong shape, leather texture; small flower with thin pedicel, the exterior of sepal without pubescence; 3-loucle ovary with pubescence, 3-splitting style; small capsule with different shape and thin pericarp. It is cultivated in China, Japan, Korea, etc.

5.5.2 var. *assamica* (Masters) Kitamura (Sealy, 1958; Chang, 1981a, 1981b, 1984; Ming, 1992)

—*C. pubicosta* Merr. (Sealy, 1958; Chang, 1981a, 1981b, 1984), **syn. nov.**; *C. sinensis* var. *kucha* Chang et Wang (Chang,1984; Ming, 1992); *C. polyneura* Chang et Tang (Chang,1984; Ming, 1992); *C. multisepala* Chang et Tang (Chang,1984; Ming, 1992)

The significant difference of var. *assamica* compared with var. *sinensis* is main semi-arbor, large and wide leaf with shining, soft leather texture; young shoot, petiole and rear side of leaf with pubescence; flower and fruit are similar. It mainly grows in Yunnan, Guangxi, Guangdong, Hainan, Taiwan, Guizhou, Sichuan and southern Hunan of China, India, Kenya and Sri Lanka, Vietnam, etc.

5.5.3 var. *pubilimba* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992)

—*C. fangchengensis* S. Y. Liang et Y. C. Zhong (Liang, 1981; Chang, 1984; Ming, 1992), **syn. nov.**; *C. angustifolia* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992); *C. parvisepala* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992); *C. ptilophylla* Chang (Chang, 1981a, 1981b, 1984; Ming, 1992), **syn. nov.**; *C. yankiangcha* Chang et Wang (Zhang *et al.*, 1990); *C. pubescens* Chang et Ye (Ye, 1987; Ming, 1992), **syn. nov.**; *C. dishiensis* F. C. Zhang (Zhang *et al.*, 1990)

Compared with var. *sinensis,* the main difference between them is the exterior of sepal, young shoot of var. *pubilimba* with dense pubescence, semi-arbor, long leaf usually thick and hard. It mainly grows in Guangxi and northeastern Guangdong, occasionally in Yunnan, Hunan of China, Vietnam and Burma, etc.

6 Evolutionary tendency of section *Thea*

The phylogenetic evolution of section *Thea* was represented by the characteristics of the locule number of ovary, splitting of style, pubescence of ovary and calyx, tree habit, branch and leaf, etc. According to the evolutionary standpoint, the species with 5-locule ovary, such as *C. tachangensis*, *C. crassicolumna*, *C. taliensis* are probably primitive and early evolutionary species. All of them have single axillary flower, thick and strong pedicel, large calyx, petal, fruit and seed, and they are high arbor with large and wide leaf.

It was supposed that the primitive ancestors of subgenus *Thea* (L.) Chang had two routes of evolution, 1) from 5-locule ovary primitive ancestor→*C. tachangensis*, 5-locule ovary without pubescence→*C. gymnogyna,* 3-locule ovary without pubescence; 2) from 5-locule ovary primitive ancestor→*C. crassicolumna*, *C. taliensis,* 5-locule ovary with pubescence→*C. sinensis* var. *assamica*, var. *pubilimba*, and var. *sinensis,* 3-locule ovary with pubescence species.

In the process of extension of the section *Thea*, different levels of differentiation had made the various species widely distributed.

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