

SOME RESEARCH ON THE GENUS *CAMELLIA* L. (THEACEAE) WITH REPRESENTATIVES IN VIETNAM

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НЕКОТОРЫЕ ИССЛЕДОВАНИЯ РОДА *CAMELLIA* L. (THEACEAE) С ПРЕДСТАВИТЕЛЯМИ ВО ВЬЕТНАМЕ

Abstract. Many studies have been conducted to classify the genus *Camellia*, yet they have not been entirely consistent. Therefore, doing research on some of the taxonomic systems of the genus *Camellia* will serve as the basis for the classification and arrangement of recently discovered species into a consistent system. A series of studies based on morphology as well as molecular biology techniques, the classification of pollen spores, and the analysis of leaf anatomy were examined. The systems based on morphological characteristics were inherited and widely recognized, thereby becoming an appropriate method to classify the genus *Camellia* with representatives in Vietnam.

Keywords: *Camellia*, classification system, taxonomy, Theaceae, Vietnam.

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Аннотация. Ранее были проведены исследования по классификации рода *Camellia*, но они не были достаточно полными. Изучение некоторых таксономических систем рода *Camellia* послужит основой для классификации и объединения недавно открытых видов в единую систему. Был изучен ряд исследований, основанных на морфологии, а также методах молекулярной биологии, классификации спор пыльцы и анализе анатомии листа. Системы, основанные на морфологических характеристиках, были унаследованы и широко признаны, что стало подходящим методом для классификации рода *Camellia* с представителями во Вьетнаме.

Ключевые слова: *Camellia*, система классификации, таксономия, Theaceae, Вьетнам.

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Introduction. The genus *Camellia* was first established by Linnaeus (1753) in “Species Plantarum” with the first species, *Thea sinensis* [26]. This species is widely used in China as a beverage with many health benefits [1]. Subsequently, the *Thea sinensis* species was renamed to *Camellia sinensis*. This is considered the foundation for later researches on the classification of the *Camellia*. Since then, the position of the genus *Camellia* has undergone many changes in the classification systems. Nowadays, it is widely accepted as a genus of the family Theaceae.

A series of recently published discoveries of the *Camellia* species [9-13; 25; 28; 34; 36; 37; 39; 40; 42-45] led to the fact that the number of species of this genus has continuously increased up to about 280 species [6; 33; 41]. The variation in the number of species as well as the diversity in the morphological characteristics has challenged the differentiation among species in this genus. Therefore, several studies have attempted to divide this genus into sections and sub-genera. Early studies of the genus *Camellia* classification based on morphological characteristics were performed and widespread [2; 5; 6; 21; 33; 48], being a common traditional classification method, which cannot be a substitute for the classification today. Due to the development of science and technology, many methods based on the anatomy and molecular biology were designed for studying the classification of this genus [19; 47; 50]. Despite the fact that many studies were conducted to classify the genus *Camellia*, these studies are not entirely consistent. Therefore, research on some of the taxonomic systems of the genus *Camellia* will serve as the basis for the classification and arrangement of recently discovered species into a consistent system. To implement this research, monographs and articles on the genus *Camellia* were collected and analyzed. This research focuses on classification systems based on

morphological characteristics as well as several systems based on anatomical features and molecular biology techniques.

Classification studies on the genus *Camellia* in the world. The first understanding of *Camellia* was a tea tree. Linnaeus (1753) reported this species in “Species Plantarum” with the name *Thea sinensis*, then renamed *Camellia sinensis* [26]. He further documented the *Camellia japonica*, an ornamental plant grown in Japan. Additionally, the author established two genera *Thea* and *Camellia*: *Thea sinensis* belonged to the genus *Thea* (Class *Polyandria Monogynia*) and *Camellia japonica* belonged to the genus *Camellia* (Class *Monadelpia Polyandria*). Seemann (1859) is the last author who remained *Thea* and *Camellia* names as two distinguished genera [49]. He based on previous research on both *Thea* and *Camellia* to document 40 different names, but from his perspective, he narrowed down this number to 12 species of two genera *Thea* and *Camellia*.

After Seemann (1859), the two genera *Thea* and *Camellia* were merged into a consistent name, *Camellia*. The authors have divided the *Camellia* into smaller groups. The first author categorizing the genus *Camellia* into sections was Dyer (1874). He divided the genus *Camellia* into two sections (*Thea* and *Camellia*), including 14 species [14]. Pierre (1887) classified 16 species into six sections (*Camelliopsis*, *Camellia*, *Euthea*, *Calpandria*, *Piquetia*, and *Stereocarpus*) [46]. Meanwhile, Cohen-Stuart (1916) erased two sections of Pierre (1887) and added one new section [8]. The system of Cohen-Stuart (1916) consisted of 38 species arranged into five sections (*Camelliopsis*, *Camellia*, *Calpandria*, *Eriandria*, and *Euthea*). Another author, Melchior (1925) enumerated 50 species belonging to the genus *Camellia* and divided them into three sub-genera *Piquetia*, *Stereocarpus*, and *Camellia*, in which the sub-genus *Camellia* was classified into five sections (*Calpandria*, *Eucamellia*, *Eriandria*, *Thea*, and *Theopsis*) [30].

Sealy (1958) classified the genus *Camellia* based on studies with morphological characteristics of Dyer (1874), Pierre (1887), and Cohen-Stuart (1916) [48]. He reused five sections of Cohen-Stuart (1916) and two sections *Stereocarpus* and *Piquetia* of Pierre (1886), which were excluded by Cohen-Stuart (1916). He also established five new sections, including *Archechamellia*, *Heterogenea*, *Paracamellia*, *Pseudocamellia*, and *Corallina*. Hence, the system of Sealy (1958) had a total of 82 species divided into 12 sections. Until now, it is still considered as a valuable reference for scientists interested in the genus *Camellia* all over the world (Table 1).

When revising Sealy’s classification system (1958), Chang (1981) retained the two sections *Archechamellia* and *Stereocarpus* [3]. However, he moved four species from the *Archechamellia* section to the new *Chrysantha* section. In 1996, he reviewed his classification system, removed the *Archechamellia* section, and retained the *Stereocarpus* [4]. However, in 1998, the author used these two sections again as a classification system [5]. Contrary to Sealy (1958), Chang removed two sections *Heterogenea*, *Camelliopsis* and added 12 new sections, including *Protocamellia*, *Pleurocarpus*, *Oleifera*, *Furfuracea*, *Tuberculata*, *Luteoflora*, *Brachyandra*, *Longipedicellata*, *Chrysantha*, *Longissima*, *Glaberrima*, and *Eriandriia* [5]. Besides, Chang’s system consisted of four sub-genera (*Protocamellia*, *Camellia*, *Thea*, and *Metacamellia*) divided into 22 sections [5]. Basically, this system is an extended upgrade from Sealy’s system (1958) (Table 1).

Ming and Bartholomew created a new classification system that was based on previous research by Sealy (1958) and Chang (1981, 1998) [31-33]. Compared to previous studies, Ming’s researches was modified a lot. The author divided the genus *Camellia* into two sub-genera and removed nine sections, including *Protocamellia*, *Pleurocarpus*, *Oleifera*, *Furfuracea*, *Luteoflora*, *Brachyandra*, *Chrysantha*, *Longissima*, and *Glaberrima*. Ming’s systems revived the section *Heterogenea* from the system of Sealy (1958) [31; 32]. The *Heterogenea* included the *Furfuracea* and several species from the *Archechamellia* and *Stereocarpus*. The section *Archechamellia* in his system consisted of the *Chrysantha* (created by Chang earlier [3]) and the *Pleurocarpus*. The *Stereocarpus* was also significantly revised, of which *C.dormoyana* was retained, the *Luteoflora* and *C.pubipetala* (from *Chrysantha*) were added (Table 1).

Recently, 32 new species were discovered in Vietnam and Southern China. Most of them are in the south of Vietnam. Orel and Curry (2015) based on the system of Sealy (1958), Chang and Bartholomew (1984), Ming and Bartholomew (2007) to arrange these species into a new system [41]. Although the system of Ming and Bartholomew (2007) (the one has significantly reduced the number of sections and the *Camellia* genus included only two sub-genera) was created after Chang and Bartholomew’s system (1984), Orel and Curry’s system (2015) retained Chang and Bartholomew’s (1984) previous four sub-genera: *Protocamellia*, *Camellia*, *Thea*, and *Metacamellia* [41]. Compared to Chang and Bartholomew’s system (1984), the sub-genus *Protocamellia* was removed two sections *Protocamellia*, *Pleurocarpus* and added four sections *Yersinia*, *Dalatia*, *Lecomtia*, and *Capitatae*. Besides, the sub-genus *Camellia* is preserved, meanwhile, the sub-genus *Thea* was added to the two sections *Lamdongia* and *Bidoupia*, and the sub-genus *Metacamellia* was added to

the section *Pierrea*. Orel and Curry's system (2015) was significantly expanded. In this system, the genus *Camellia* was composed of up to 27 sections in which seven sections were newly created (Table 1).

Table 1

The main classification systems of the genus *Camellia* in the world
(underlines are sub-genera, italics are sections)

Sealy (1958)	Chang (1981, 1998), Chang and Bartholomew (1984)	Ming (1999, 2000), Ming and Bartholomew (2007)	Orel and Curry (2015)
<i>Archechamellia</i> Sealy <i>Stereocarpus</i> (Pierre) Sealy <i>Heterogenea</i> Sealy <i>Piquetia</i> (Pierre) Sealy <i>Pseudocamellia</i> Sealy <i>Paracamellia</i> Sealy <i>Camellia</i> (L.) Dyer <i>Corallina</i> Sealy <i>Calpandria</i> (Bl.) Coh. St. <i>Thea</i> (L.) Dyer <i>Theopsis</i> Coh. St. <i>Camelliopsis</i> (Pierre) Sealy	<u>Protocamellia</u> Chang <i>Archechamellia</i> Sealy <i>Stereocarpus</i> (Pierre) Sealy <i>Protocamellia</i> Chang <i>Pleurocarpus</i> Chang <i>Piquetia</i> (Pierre) Sealy <u>Camellia</u> Chang <i>Oleifera</i> Chang <i>Furfuracea</i> Chang <i>Paracamellia</i> Sealy <i>Pseudocamellia</i> Sealy <i>Tuberculata</i> Chang <i>Luteoflora</i> Chang <i>Camellia</i> (L.) Dyer <u>Thea</u> (L.) Chang <i>Corallina</i> Sealy <i>Brachyandra</i> Chang <i>Longipedicellata</i> Chang <i>Chrysantha</i> Chang <i>Calpandria</i> (Bl.) Coh. St. <i>Thea</i> (L.) Dyer <i>Longissima</i> Chang <i>Glaberrima</i> Chang <u>Metacamellia</u> Chang <i>Theopsis</i> Coh. St. <i>Eriandriia</i> Coh. St. <i>Camelliopsis</i> (Pierre) Sealy	<u>Thea</u> (L.) Chang <i>Archechamellia</i> Sealy Syn. sect. <i>Chrysantha</i> Chang <i>Thea</i> (L.) Dyer <i>Cylindrica</i> Ming <i>Piquatia</i> (Pierre) Sealy <i>Corallina</i> Sealy <i>Theopsis</i> Coh. St. <i>Eriandriia</i> Coh. St. <i>Longipedicellata</i> Chang <u>Camellia</u> Chang <i>Stereocarpus</i> (Pierre) Sealy <i>Heterogenea</i> Sealy Syn. sect. <i>Archechamellia</i> Sealy (sensu H.T. Chang 1981, 1998) Syn. sect. <i>Stereocarpus</i> (Pierre) Sealy (sensu H.T. Chang 1981, 1998) Syn. sect. <i>Furfuracea</i> Chang <i>Paracamellia</i> Sealy <i>Tuberculata</i> Chang <i>Camellia</i> (L.) Dyer <i>Calpandria</i> (Bl.) Pierre	<u>Protocamellia</u> Chang <i>Archechamellia</i> Sealy <i>Stereocarpus</i> (Pierre) Sealy <i>Piquetia</i> (Pierre) Sealy <i>Yersinia</i> Orel <i>Dalatia</i> Orel <i>Lecomtia</i> Orel <i>Capitatae</i> Orel <u>Camellia</u> Chang <i>Oleifera</i> Chang <i>Furfuracea</i> Chang <i>Paracamellia</i> Sealy <i>Pseudocamellia</i> Sealy <i>Tuberculata</i> Chang <i>Luteoflora</i> Chang <i>Camellia</i> (L.) Dyer <u>Thea</u> (L.) Chang <i>Corallina</i> Sealy <i>Brachyandra</i> Chang <i>Longipedicellata</i> Chang <i>Chrysantha</i> Chang <i>Calpandria</i> (Bl.) Coh. St. <i>Thea</i> (L.) Dyer <i>Longissima</i> Chang <i>Glaberrima</i> Chang <i>Lamdongia</i> Orel <i>Bidoupia</i> Orel, Curry & Luu <u>Metacamellia</u> Chang <i>Theopsis</i> Coh. St. <i>Eriandriia</i> Coh. St. <i>Pierrea</i> Orel

In addition to morphological classification studies, classification methods based on molecular biology techniques, the classification of pollen spores, and the analysis of leaf anatomy have been used. The classification results of Vijayan et al. (2009) published from the nrITS sequence analysis of 112 *Camellia* species gave both consensus and conflict results compared to previous morphological classification systems [50]. Although the study suggested the polyphyletic nature of the sections *Camellia*, *Paracamellia*, *Pseudocamellia*, and *Tuberculata* as well as the paraphyletic nature of the section *Chrysantha*, it did not support the sectional status of three small sections, *Archechamellia*, *Piquetia*, and *Stereocarpus*.

Jiang et al. (2010) conducted a multivariate analysis of leaf shape, anatomy, and Fourier Transform Infrared (FTIR) data of 27 *Camellia* species with secretory structure (from the sections *Archechamellia*, *Stereocarpus*, *Furfuracea*, and *Chrysantha* according to Chang's system (1998)), together with three species from related genera, *Gordonia* and *Tutcheria* (Theaceae), to clarify some taxonomic problems [19]. This study indicated that integrated leaf characters based on leaf shape, anatomy, and FTIR data were useful in the taxonomic treatment of *Camellia* species with secretory structures. The results of this study also tended to support that the *Chrysantha* species should not be merged into section *Archechamellia*. Moreover, Jiang et al. (2017) classified *Camellia* based on the color intensity of red, green, and blue leaves with assistive devices [20]. This study aimed to accurately distinguish 68 species of the *Camellia* from the five sections *Furfuracea*, *Paracamellia*, *Tuberculata*, *Theopsis*, and *Camellia* according to Chang's classification (1998). As a result, a hierarchical dendrogram and clustering of sections were created.

Lu et al. (2012) used the leaf morphology and venation characters from 93 species of the genus *Camellia* in five sections, including *Furfuracea*, *Paracamellia*, *Tuberculata*, *Camellia*, and *Theopsis* [27]. This study resulted in a clustering dendrogram of sections similar to the previous study. Thus, the analysis of leaf structure

data is useful for identifying *Camellia* species. Lu et al.'s study (2012) complements the traditional studies that used earlier leaf morphological characteristics [27].

Classification studies on the genus *Camellia* in Vietnam. The earliest study of the genus *Camellia* in Vietnam was of the French author Lanessan (1886) with the first two species *Thea dormoyana* and *Thea piquetiana* [22]. Later, these two species were grouped into the genus *Camellia*. During the 20th century, the number of authors published researches about *Camellia* species in Vietnam increased. Gagnepain (1939) additionally published three species *Thea amplexicaulis*, *Thea tonkinensis*, and *Thea flava* [15]. Meanwhile, Chevalier (1919) published the next two species *Thea fleuryi* and *Thea gilberti* found in Vietnam [7]. Especially, these are also the first species of the genus *Camellia* in the world being described as having yellow flowers. In the monograph of Sealy (1958) documented 27 species of the genus *Camellia* in Vietnam [48], including *C. amplexicaulis*, *C. pleurocarpa*, *C. krempfii*, *C. dormoyana*, *C. piquetiana*, *C. oleifera*, *C. furfuracea*, *C. gaudichaudii*, *C. kissi*, *C. corallina*, *Thea yersini*, *Thea nervosa*, *C. nematodea*, *C. gilberti*, *C. flava*, *C. euphlebia*, *C. petelotii*, *C. indochinensis*, *C. tonkinensis*, *C. fleuryi*, *C. pubicosta*, *C. sinensis*, *C. gracilipes*, *C. forrestii*, *C. tsaii*, *C. tsingpienensis*, and *C. caudata*.

The latter period marked the presence of Vietnamese authors. The authors with typical research on the genus *Camellia* can be mentioned: Ho (1991, 1999) with “Flora of Vietnam”, Ninh (2002) with “Diversity of *Camellia* species in Vietnam”, and most recently Hien (2017) with the study on the Theaceae family in “Flora of Vietnam” [16; 17; 18; 35]. Ho (1991, 1999) classified the Theaceae family into ten genera: *Anneslea*, *Archytea*, *Pyrenaria*, *Camellia*, *Gordonia*, *Eurya*, *Temstroemia*, *Tristylum*, *Adinandra*, and *Hartia* [17; 18]. Of these, the genus *Camellia* has a superior ovary, an unbundled pistil, large flowers with many bracteoles like sepals, a capsule, and round wingless seeds. He also divided the *Camellia* into four sub-genera: *Protocamellia* (*Stereocarpus* and *Archechamellia*), *Camellia* (*Camellia*), *Thea*, and *Metacamellia*. The study of Ho (1999) has recorded and described 30 *Camellia* species that existed in the territory of Vietnam [18]. This is also considered the first comprehensive systematic announcement dedicated to *Camellia* species in Vietnam. However, this system was just an application of Chang and Bartholomew’s system (1984) to the *Camellia* species in Vietnam. According to Ninh (2002), there are 50 species of *Camellia* in Vietnam [35]. He divided this genus into four sub-genera *Protocamellia* (*Archechamellia*, *Stereocarpus*, and *Piquetia*), *Camellia* (*Oleifera*, *Furfuracea*, *Paracamellia*, and *Camellia*), *Thea* (*Corallina*, *Branchyandra*, *Longipedicellata*, *Chrysantha*, *Thea*, and *Longissima*), and *Metacamellia* (*Theopsis* and *Eriandria*) [35]. Nonetheless, Ninh’s research (2002) did not provide criteria for classification, as well as classification keys for taxonomic orders in the genus *Camellia*, and it is based on the system of Chang and Bartholomew (1984) as well. Although Ninh’s system (2002) also included four genera, he classified and expanded the genus *Camellia* into more sections than the system of Ho (1999) (Table 2).

Table 2

Some taxonomy systems of the genus *Camellia* with representatives in Vietnam
(underlines are sub-genera, italics are sections)

Ho (1999)	Ninh (2002)	Hien (2017)
<p><u>Camellia</u> Chang <i>Camellia</i> (L.) Dyer</p> <p><u>Thea</u> (L.) Chang <u>Protocamellia</u> <u>Chang</u> <i>Archechamellia</i> Sealy <i>Stereocarpus</i> (Pierre) Sealy</p> <p><u>Metacamellia</u> Chang</p>	<p><u>Camellia</u> Chang <i>Camellia</i> (L.) Dyer <i>Oleifera</i> Chang <i>Furfuracea</i> Chang <i>Paracamellia</i> Sealy</p> <p><u>Thea</u> (L.) Chang <i>Corallina</i> Sealy <i>Brachyandra</i> Chang <i>Longipedicellata</i> Chang <i>Chrysantha</i> Chang <i>Thea</i> (L.) Dyer <i>Longissima</i> Chang</p> <p><u>Protocamellia</u> Chang <i>Archechamellia</i> Sealy <i>Stereocarpus</i> (Pierre) Sealy <i>Piquetia</i> (Pierre) Sealy</p> <p><u>Metacamellia</u> Chang <i>Theopsis</i> Coh. St. <i>Eriandria</i> Coh. St.</p>	<p><u>Camellia</u> Chang <i>Camellia</i> (L.) Dyer <i>Heterogenea</i> Sealy <i>Stereocarpus</i> (Pierre) Sealy <i>Paracamellia</i> Sealy</p> <p><u>Thea</u> (L.) Chang <i>Piquatia</i> (Pierre) Sealy <i>Archechamellia</i> Sealy <i>Corallina</i> Sealy <i>Cylindrica</i> Ming <i>Thea</i> (L.) Dyer <i>Longipedicellata</i> Chang <i>Theopsis</i> Coh. St. <i>Eriandria</i> Coh. St.</p>

Hien (2017) reported 54 species of *Camellia* in Vietnam [16]. His research was based on Ming's classification system (1999, 2000), dividing the genus *Camellia* in Vietnam into two sub-genera and 12 sections. The sub-genus *Thea* consisted of species with clear peduncle, bracts attached to the peduncle, as well as not deciduous bracts and sepals. This sub-genus included sections *Piquetia*, *Archechamellia*, *Corallina*, *Cylindricea*, *Thea*, *Longipedicellata*, *Theopsis*, and *Eriandria*. The sub-genus *Camellia* was composed of species with almost sessile flowers, sepals closely attached bracts, as well as deciduous bracts and sepals. To divide it into sections, the author based on characteristics such as whether stigmas stick together or separate, the size of the leaf blade is large, medium, or small, and the bracts will soon fall or not. The number of bracts was also used to divide into sections *Heterogenea*, *Stereocarpus*, *Camellia*, and *Paracamellia* (Table 2).

There are also some other studies on the *Camellia* in Vietnam that can be mentioned. Ninh (2003) documented 16 species of the *Camellia* with yellow flowers mostly distributed in northern Vietnam [38]. However, his research does not represent a large number of *Camellia* species. Moreover, Ninh's publication did not accompany any descriptions or classifications according to the system. Le and Dung's collection (2016) of all yellow *Camellia* species in Vietnam showed that Vietnam had 34 species of *Camellia* with yellow flowers [23]. However, except for the *Camellia* with yellow flowers, their study did not report any other *Camellia* species, as well as classified them into the classification system. Manh et al. (2019) have reported 52 *Camellia* species with yellow flowers distributed in South China and Vietnam [29]. This study only documented approximately 40 *Camellia* species existing in Vietnam without determining the exact number of this species in Vietnam. Most recently, Le et al. (2020) has published a list of species of the Theaceae in Vietnam, including the document of 95 species of the *Camellia* in Vietnam [24]. The number of the *Camellia* species is very large, but the authors only based on documents without mentioning the research fieldwork. In other words, the authors did not study in detail the taxonomy of the genus *Camellia*.

It can be stated that the genus *Camellia* is the largest genus in the family Theaceae that many scientists have concerned about. Many new species were published, many methods were used, and many classification systems were applied. In particular, the classification with morphological characteristics is still considered as the main method which basically cannot be replaced, especially in Vietnamese conditions. Although there are so many classification systems of the genus *Camellia* in the world and in Vietnam, the ones of Sealy (1958), Chang (1981, 1998), Chang and Bartholomew (1984), and most recently Orel and Curry (2015) are widely recognized. In Vietnam, there are three main systems including Ho (1999), Ninh (2002) and Hien (2017) (Table 2). In which there are two systems of Ho (1999) and Ninh (2002) based on Chang's system (1998), which was extended by Orel and Curry (2015). These systems are inherited and widely used to classify the genus *Camellia* with representatives in Vietnam.

Conclusions. This is the first integrated study of the genus *Camellia* research with representatives in Vietnam. Many classification systems as well as methods have been applied to the classification of the genus *Camellia*. The traditional classification method based on morphological characteristics is still widely accepted and cannot be replaced in the classification of the genus *Camellia* both in the world and in Vietnam. Nonetheless, there were not many studies that specialized in classifying the genus *Camellia* was conducted by Vietnamese researchers. Thus, this study provided an overview of the studies for the genus *Camellia* with representatives from Vietnam, setting the stage for selecting a suitable system that will be used for the classification study of the genus *Camellia* of Vietnam.

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