Analyses of Chloroplast Genomic and Morphological Evolutionomy of Yulania Subsect. Cylindricae (Magnoliaceae)

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Abstract: To scientifically settle the puzzle of origin of fruit plants, the chloroplast genomic sequences of three species of Yulania subsect. Cylindricae (Spongb.) D. L. Fu, subsect. comb. nov. (Magnoliaceae) were determined, which were compared with some taxa by means of the typical algorithm, a new method for genomic evolutionomy based on the evolutionary continuity principle. The results indicated that among some representative species of Gymnospermophyta, Yulania puberula D. L. Fu, sp. nov. has the closest relatively evolutionary relationship with Ginkgo biloba, not with the species of Cycas, Welwitschia or Ephedra, which indicated that fruit plants originated from Ginkgoopsida, not from Cycadopsida thought by the euanthium-theory or Chlamydomopsida thought by the pseudoanthium-theory. Among some representative species of Fructophyta, Ginkgo biloba has the closest relatively evolutionary relationship with Yulania puberula indicating that the new species is the relatively most primitive species of fruit plants, which is consistent with the results of morphological evolutionomy. The evolutionary system of Magnoliaceae includes 4 natural genera: Yulania Spach, Magnolia L., Michelia L. and Liriodendron L., whose boundaries all are PHS(17bp)=0.93. Furthermore Yulania subsect. Cylindricae and its three species were described or emended. The holotype of new species of Yulania puberula was designated, whose main typici-evolutionary characters, including diagnostic differences and particularities, was given and illustrated. The epitype of Y. shizhenii was designated and four synonyms of Y. cylindrica were listed. Typical algorithm is a scientific method of genomic evolutionomy and a scientifically new tool to solve the puzzle of evolutionomy of fruit plants.

Keywords: Typical Algorithm, Chloroplast Complete Genome, Evolutionomy, Yulania Puberula, Yulania Subsect. Cylindricae, Magnoliaceae, Fructophyta, New Species

1. Introduction

Fructophyta D. L. Fu & H. Fu [1], a new division built in 2018, including all fruit or flowering plants, commonly called angiosperms, occupy the highest evolutionary phylum taxa and an important position in terrestrial ecosystems and human wellbeing. The origin and evolution of fruit plants remain a mystery, as that the British plant taxonomists P. H. Davis and V. H. Heywood pointed out in their famous book Principles of Angiosperm Taxonomy, the origin and phylogeny of angiosperms have puzzled plant systematics for quite some time. The famous botanist, Professor Zhang Hongda [2] also
pointed out that: "because of the long age, it is rare to find the complete fossils of original flowering plants belonging to the Triassic... at present, that we do not have a rational evolutionary system of flowering plant is understandable."

There are two opposite theories about the origin of fruit plants: euanthium-theory and pseudoanthium-theory. The representative systems of pseudoanthium-theory were Engler system [3] and H. D. Zhang system [2], which thought flowering plants originated from Chlamydopspermopsida of Gymnospermophyta. Casuarinaceae R. Br. are the most primitive taxa in Engler system [3] and Trochodendraceae Prant. are the most primitive taxa in H. D. Zhang system [2]. The representative systems of euanthium-theory were Hutchinson system [4], Takhtajan system [5], Cronquist system [6] and C. Y. Wu System [7], which thought flowering plants originated from Cycadopsida of Gymnospermophyta. Winteraceae Lindley are the most primitive taxa of flowering plants in Takhtajan system [5] and Cronquist system [6], and Magnoliaceae Juss. are the most primitive taxa of flowering plants in Hutchinson system [4] and C. Y. Wu system [7].

The rapid development of molecular biology has promoted the development of plant systematics. The main basis of plant systematics is the "tree of life" of Darwin's theory of evolution [1], based on the theory of "common ancestor" and "germogenesis" [8]. The system can show phylogenetic relationships among different beings, but cannot show evolutionary relationships, which can lead to a subjective system sometimes [1]. For example, the APG system considers the family Amborellaceae Pinch. as the most primitive angiosperm and establish taxonomic taxa such as Eudicots and Core eudicots [8]. These unscientific conclusions and taxa are concrete manifestations of the theoretical limitations. The phylogenetic theory itself offers no scientific ideas and methods for understanding the evolutionary veins of fruit plants, because how to find and process some "noise [5]" occurred in the evolution of fruit plants is still a puzzle (here, "noise" means DNA sequences not having important evolutionary significance).

How scientifically settle the puzzle of origin of fruit plants? The chloroplast genomic sequences of three primitive species of Yulania subsect. Cylindricae (Spongb.) D. L. Fu, subsect. comb. nov. (Magnoliaceae Juss.) were determined and compared with some primitive taxa by means of the typical algorithm based on the evolutionary continuity principle [1]. The results and analyses are as follows:

2. Materials and Methods

2.1. Chloroplast Genome Sequencing, Assembly and Annotation

Total genomic DNA was isolated from silica-dried leaves of three species of Yulania subsect. Cylindricae: Y. cylindrica (Wils.) D. L. Fu from Xiuning county of Anhui province, Y. shizhenii D. L. Fu et F. W. Li from Chengdu City of Sichuan province and new species of Y. puberula D. L. Fu from Mountain Wudang in Hubei Province, using a modified CTAB method [9]. After quantification and qualification, a paired-end library was constructed, and high-throughput sequencing was performed using the Illumina Hiseq 2500 platform (Lemont, IL, USA). After cleaning the raw data, all remaining high quality sequences were assembled into contigs using de novo assembly, and the complete chloroplast genomes were assembled using the software SPAdes v3.9.0. The circular map of fully annotated genomes were drawn in OGDRAW v1.2 [10]. All three chloroplast genomes of Yulania subsect. Cylindricae were deposited in the GenBank database.

2.2. Evolutionary Analyses of Chloroplast Complete Genomes

By analyzing the morphological characters using evolutionary continuity principle of Evolutionomy [1], the chloroplast genomes of three species of Yulania subsect. Cylindricae (Spongb.) D. L. Fu, subsect. comb. nov. (Magnoliaceae) were compared with other primitive groups such as Amborellaceae Pinch., Winteraceae Lindley, Trochodendraceae Prant., in order to scientifically determine the evolutionary position of Yulania subsect. Cylindricae (Spongb.) D. L. Fu in the evolution of fruit plants. The evolutionary analyses of chloroplast genomes mainly adopted the typical algorithm, by comparing EVS = the evolutionary similarities between the designated type and species or taxa, and PHS = the phylogenetic similarity between the designated type and species or taxa, to determine the relatively evolutionary relationship among different taxa. The formulas are as follows:

\[ \text{EVS} = \frac{\text{SEVL}}{\text{AEVL}} \]
\[ \text{PHS} = \frac{\text{APHL}}{\text{SPHL}} \]

\[ \text{EVS} = \text{evolutionary similarity}; \text{SEVL} = \text{same evolutionary loci between the type and taxon}; \text{AEVL} = \text{all evolutionary loci between the type and taxon} \]
\[ \text{PHS} = \text{phylogenetic similarity}; \text{SPHL} = \text{all phylogenetic loci between the type and taxon}; \text{APHL} = \text{all phylogenetic loci of the type} \]

3. Chloroplast Genomes of Three Species of Yulania Subsect. Cylindricae

The chloroplast genomes of three species of Yulania, similar to the chloroplast genomes of other higher plants, contains two inverted repeats, IRA and IRB, which make the entire genes component into four parts, the remaining LSC large single copy area and SSC small single copy area. For the basic information of genomic length, partition length, GC content, and number of coding genes of chloroplasts of three species, see Table 1 and Figure 1.
Table 1. Basic characteristics of chloroplast genomes of three species of Yulania subsect. Cylindricae.

| Chloroplast genome       | Yulania cylindrica | Yulania puberula | Yulania shizhenii |
|--------------------------|--------------------|------------------|-------------------|
| Total length             | 160,079 bp         | 160,067 bp       | 160,062 bp        |
| LSC                      | 88,118 bp          | 88,108 bp        | 88,103 bp         |
| SSC                      | 18,779 bp          | 18,779 bp        | 18,779 bp         |
| GC%                      | 39.3%              | 39.3%            | 39.3%             |

Table 2. List of genes present in the chloroplast genomes of three species of Yulania subsect. Cylindricae.

| Function                | Group of genes              | Gene names                        |
|-------------------------|-----------------------------|-----------------------------------|
| ATP synthase            | atpA, atpB, atpE, atpF*, atpH, atpI |
| Cytochrome b/f complex  | psaA, psaB, psaC, psaI      |
| NADH dehydrogenase      | ndhA*, ndhB*, ndhC, ndhD, ndhE, ndhF, ndhG, ndhH, ndhI, ndhJ, ndhK |
| Photosystem I           | psbA, psbB, psbC, psbD, psbE, psbF, psbH, psbI, psbK, psbL, psbM, psbN, psbO, psbZ |
| Photosystem II          | psbA, psbB, psbC, psbD, psbE, psbF, psbH, psbI, psbK, psbL, psbM, psbN, psbO, psbZ |
| Proteins of unknown function | ycf1*, ycf2, ycf3*, ycf4 |
| Ribosomal proteins (SSU)| rps2, rps3, rps4, rps7, rps8, rps11, rps12*, rps14, rps15, rps16, rps18, rps19 |
| Ribosomal proteins (LSU)| rpl2*, rpl14, rpl16, rpl20, rpl22, rpl23, rpl32, rpl33, rpl36 |
| Ribosomal RNAs          | rrn4.5*, rrn5*, rrn16*, rrn23* |
| RNA polymerase          | rpoA, rpoB, rpoC1*, rpoC2 |

*gene containing a single intron, **gene containing two introns, #trans-splicing gene, ’Two gene copies in Irs

The complete chloroplast genomes of Yulania cylindrica, Y. puberula and Y. shizhenii are 160,079bp, 160,067bp and 160,062 bp in length, respectively. They are all encoded 128 genes. Among them, there are 83 protein coding genes, 8 rRNA genes and 37 tRNAs. trnK-UUU, rps16, trnG-UCC, atpF, rpoC1, trnL-UAA, trnV-UAC, petB, petD, rpl16, rpl2, ndhB, trnG-AUA, trnA-UGC, ndhA genes with an intron for each gene, clpP, ycf3 gene with two introns and the rps12 is trans-splicing gene, see Table 2 and Figure 1.

Figure 1. Chloroplast genome map of 3 species of Yulania subsect. Cylindricae (Magnoliaceae). The genes inside and outside the circle are transcribed in the clockwise and counterclockwise directions, respectively. Genes belonging to different functional groups are shown in different colors. The thick lines indicate the extent of the inverted repeats (IRA and IRB) that separate the genomes into small single-copy (SSC) and large single-copy (LSC) regions.
4. Origin of Fruit Plants

According to the evolutionary continuity principle, it is known that Fructophyta D. L. Fu & H. Fu originated from Gymnospermophyta D. L. Fu & H. Fu [1], but we don’t know which taxa of Gymnospermophyta have the closest evolutionary relationships with fruit plants especially about the main evolutionary vein of origin and evolution of fruits. Because the new species Yulania puberula D. L. Fu of subsect. Cylindricae (Spong.) D. L. Fu has the most primitive peruloid bracts (see Figure 3(7)), so it is selected as the type of fruit plants and calculated the evolutionary similarity and the phylogenetic similarity among the samples of Gymnospermophyta from NCBI, the results are shown in Table 4.

5. Relatively Original Species of Fruit Plants

5.1. Relatively Evolutionary Relationships Among Different Classes or Subclasses of Fructophyta

For only one species survived in Ginkgoopsida, so Ginkgo biloba is consequentially selected as the type of Gymnospermophyta. To represent 5 classes and 20 subclasses, 22 species were selected and calculated the evolutionary similarity and the phylogenetic similarity with the type, the results are shown in Table 4.

It can be seen from Table 4 that EVS and PHS between Ginkgo biloba and Yulania puberula is 0.2776 and 0.0608 respectively, obvious higher than other species such as Trochodendron aralioides and Amborella trichopoda. So Magnoliidae is primitive subclass of fruit plants. It is not supported that Trochodendron Siebold & Zucc. are original family in H. D. Zhang system and Amborella Baill. Are original family in APG system by chloroplast genomic evolutionomy.

5.2. Relatively Evolutionary Relationships Among Different Families of Magnoliidae

For only 10 families having chloroplast complete genomes in NCBI, 10 species were selected and calculated the EVS and PHS with Ginkgo biloba, the results are shown in Table 5.

It can be seen from Table 5 that there are 1,691 evolutionary loci (SNB = 21bp) between the species of Yulania puberula and gymnosperms, of which 453 are the same with the species of Ginkgo biloba and the EVS is 0.2679, which is higher than other gymnosperm samples. Therefore Yulania puberula and Ginkgo biloba has the closest relatively evolutionary relationship. PHS between Yulania puberula and Ginkgo biloba (PHS=0.0548) is also obviously higher than other samples of gymnosperms. According to the evolutionary continuity principle, it can be determined that fruit plants originated from Ginkgoopsida, not from Cycadopsida thought by the euanthium-theory or Chlamydopsermopsida by the pseudoanthium-theory.
5.3. Relatively Evolutionary Relationships Among Different Genera of Magnoliaceae

To scientifically reflect the relatively evolutionary relationships among different genera of Magnoliaceae, 28 species having chloroplast complete genomes in NCBI were selected and calculated the evolutionary similarity and the phylogenetic similarity with the type of Ginkgo biloba, the results are shown in Table 6.

It can be seen from Table 6 that EVS between Ginkgo biloba and Yulania diva is 0.0859 obvious higher than PHS = 0.0712 between Yulania cylindrica and Yulania puberula and Ginkgo biloba is PHS = 0.0713, which is similar to EVS = 0.0255, but PHS between Ginkgo biloba and 10 species of Yulania were calculated, and the results are shown in Table 7:

5.4. Relatively Evolutionary Relationships Among Species of Genus Yulania

In order to determine the relatively evolutionary relationship among the species of genus of Yulania, the EVS and PHS between Ginkgo biloba and 10 species of Yulania Spach were calculated, and the results are shown in Table 7:

It can be seen from Table 7 that Yulania puberula and Yulania cylindrica have the closest relatively evolutionary relationships with Ginkgo biloba, and the evolutionary similarities are same as EVS = 0.2525, but PHS between Yulania puberula and Ginkgo biloba is PHS = 0.0713, which is higher than PHS = 0.0712 between Yulania cylindrica and Ginkgo biloba, so Yulania puberula has the closest evolutionary relationship and phylogenetic relationship with Ginkgo biloba among species of the genus of Yulania Spach.

So it can be concluded that Magnoliaceae Juss. are the most primitive family, Yulania Spach is the most primitive genus, and Yulania puberula is the most primitive species.
genus and *Yulania puberula* is the most primitive species of *Fructophyta*.

### Table 6. EVS and PHS of chloroplast genomes between Ginkgo biloba and different species of Magnoliaceae Juss.

| Phylum | Species name and Genomic number of NCBI | EVL/17bp | EVS | PHL/17bp | PHS |
|--------|----------------------------------------|----------|-----|----------|-----|
| Gymnospermophyta | Ginkgo biloba _JN867578.1_ | 1153 | 1 | 138938 | 1 |
| Fructophyta | Yulania diva? _NC023242.1_ | 99 | 0.0859 | 9900 | 0.0713 |
| Yulania puberula | 97 | 0.0841 | 9905 | 0.0713 |
| Yulania cylindrica | 97 | 0.0841 | 9894 | 0.0712 |
| Yulania salicifolia _NC023240.1_ | 97 | 0.0841 | 9909 | 0.0713 |
| Magnolia grandiflora _NC020318.1_ | 97 | 0.0841 | 9941 | 0.0715 |
| Magnolia dealbata _NC023235.1_ | 96 | 0.0833 | 9883 | 0.0711 |
| Yulania shizhenii | 96 | 0.0833 | 9903 | 0.0713 |
| Liriodendron tulipifera _DQ899947.1_ | 96 | 0.0833 | 9901 | 0.0713 |
| Magnolia officinalis _NC020316.1_ | 95 | 0.0824 | 9906 | 0.0713 |
| Yulania demudata _JN867577.1_ | 95 | 0.0824 | 9894 | 0.0712 |
| Yulania liliflora _JX280397.1_ | 95 | 0.0824 | 9658 | 0.0695 |
| Yulania biondii _KY085894.1_ | 95 | 0.0824 | 9886 | 0.0712 |
| Magnolia kwangsiensis _HM775382.1_ | 95 | 0.0824 | 9922 | 0.0714 |
| Michelia laevifolia _NC035956.1_ | 95 | 0.0824 | 9909 | 0.0713 |
| Liriodendron chinense _NC030504.1_ | 95 | 0.0824 | 9903 | 0.0713 |
| Magnolia acuminata _JX280391.1_ | 94 | 0.0815 | 9905 | 0.0713 |
| Magnolia pyramidata _NC023236.1_ | 93 | 0.0807 | 9920 | 0.0714 |
| Magnolia sinica _NC023241.1_ | 93 | 0.0807 | 9887 | 0.0712 |
| Magnolia danyi _NC037004.1_ | 92 | 0.0798 | 9896 | 0.0710 |
| Magnolia tripetala _NC024027.1_ | 92 | 0.0798 | 9879 | 0.0711 |
| Yulania kobus _NC023237.1_ | 92 | 0.0798 | 9877 | 0.0711 |
| Michelia odorata _NC023239.1_ | 92 | 0.0798 | 9868 | 0.071 |
| Magnolia yunnanensis _NC024545.1_ | 92 | 0.0798 | 9896 | 0.0712 |
| Magnolia glaucifolia _NC037003.1_ | 91 | 0.0789 | 9876 | 0.0711 |
| Magnolia ducloixii _NC037002.1_ | 91 | 0.0789 | 9899 | 0.0712 |
| Magnolia fordiana _MF990562.1_ | 91 | 0.0789 | 9871 | 0.071 |
| Michelia cathcartii _NC023234.1_ | 90 | 0.0781 | 9876 | 0.0711 |
| Magnolia insignis _MF990566.1_ | 89 | 0.0772 | 9893 | 0.0712 |

### Table 7. EVS and PHS between Ginkgo biloba and different species of *Yulania* Spach.

| Species name and Genomic number of NCBI | EVL/17bp | EVS | PHL/17bp | PHS |
|----------------------------------------|----------|-----|----------|-----|
| Ginkgo biloba _JN867578.1_ | 982 | 1 | 138938 | 1 |
| Yulania puberula | 25 | 0.0255 | 9905 | 0.0713 |
| Yulania cylindrica | 25 | 0.0255 | 9894 | 0.0712 |
| Yulania shizhenii | 24 | 0.0244 | 9903 | 0.0713 |
| Yulania diva? _NC023242.1_ | 24 | 0.0244 | 9900 | 0.0713 |
| Yulania salicifolia _NC023240.1_ | 24 | 0.0244 | 9909 | 0.0713 |
| Yulania liliflora _JX280397.1_ | 23 | 0.0234 | 9658 | 0.0695 |
| Yulania biondii _KY085894.1_ | 23 | 0.0234 | 9886 | 0.0712 |
| Yulania acuminata _JX280391.1_ | 22 | 0.0224 | 9905 | 0.0713 |
| Yulania demudata _JN867577.1_ | 22 | 0.0224 | 9894 | 0.0712 |
| Yulania kobus _NC023237.1_ | 21 | 0.0214 | 9877 | 0.0711 |

### Table 8. PHS and EVS of chloroplast genomes between Yulania demudata and different species of Magnoliaceae Juss.

| Species name and cpDNA number of NCBI | PHL/17bp | PHS | EVL/17bp | EVS |
|---------------------------------------|----------|-----|----------|-----|
| Yulania demudata _JN867577.1_ | 133206 | 1 | 4155 | 1 |
| Yulania cylindrica | 131736 | 0.99 | 4084 | 0.98 |
| Yulania puberula | 131551 | 0.99 | 4074 | 0.98 |
| Yulania shizhenii | 131460 | 0.99 | 4068 | 0.98 |
| Yulania liliflora _JX280397.1_ | 129270 | 0.97 | 3979 | 0.96 |
| Yulania salicifolia _NC023240.1_ | 127070 | 0.95 | 3756 | 0.90 |
| Yulania diva? _NC023242.1_ | 126820 | 0.95 | 3722 | 0.90 |
| Yulania biondii _KY085894.1_ | 126313 | 0.95 | 3667 | 0.88 |
| Yulania kobus _NC023237.1_ | 125689 | 0.94 | 3632 | 0.87 |
| Yulania acuminata _JX280391.1_ | 123659 | 0.93 | 3505 | 0.84 |
| Magnolia yunnanensis _NC024545.1_ | 122609 | 0.92 | 3415 | 0.82 |
| Magnolia sinica _NC023241.1_ | 122465 | 0.92 | 3389 | 0.82 |
| Magnolia dealbata _NC023235.1_ | 121824 | 0.91 | 3366 | 0.81 |
| Magnolia fordiana _MF990562.1_ | 121647 | 0.91 | 3332 | 0.80 |
| Magnolia danyi _NC037004.1_ | 121609 | 0.91 | 3325 | 0.80 |
| Magnolia insignis _MF990566.1_ | 121607 | 0.91 | 3329 | 0.80 |
| Species name and cpDNA number of NCBI | PHL/17bp | PHS | EVL/17bp | EVS |
|--------------------------------------|----------|-----|----------|-----|
| Magnolia duclouxii_NC037002.1        | 121580   | 0.91| 3332     | 0.80|
| Magnolia tripetala_NC024027.1        | 121578   | 0.91| 3316     | 0.80|
| Michelia laevifolia_NC035956.1       | 121575   | 0.91| 3328     | 0.80|
| Magnolia kwangsiensis_HM775382.1     | 121536   | 0.91| 3361     | 0.81|
| Magnolia glaucifolia_NC037003.1      | 121499   | 0.91| 3324     | 0.80|
| Magnolia grandiflora_NC020318.1      | 121332   | 0.91| 3326     | 0.80|
| Magnolia pyramidata_NC023236.1       | 121260   | 0.91| 3321     | 0.80|
| Michelia cathcartii_NC023234.1       | 121126   | 0.91| 3307     | 0.80|
| Magnolia officinalis_NC020316.1      | 121121   | 0.91| 3273     | 0.79|
| Michelia odora_NC023239.1            | 121014   | 0.91| 3294     | 0.79|
| Liriodendron tulipifera_DQ899947.1   | 103965   | 0.78| 2039     | 0.49|
| Liriodendron chinense_NC030504.1     | 103689   | 0.78| 2009     | 0.48|

Table 9. PHS and EVS of chloroplast genomes between Magnolia fordiana and different species of Magnoliaceae Juss.

| Species name and cpDNA number of NCBI | PHL/17bp | PHS | EVL17bp | EVS |
|--------------------------------------|----------|-----|----------|-----|
| Magnolia fordiana_MF990562.1         | 133165   | 1   | 4187     | 1   |
| Magnolia dandyi_NC037004.1           | 123460   | 0.99| 4136     | 0.99|
| Magnolia glaucifolia_NC037003.1      | 123385   | 0.99| 4134     | 0.99|
| Magnolia duclouxii_NC037002.1        | 120855   | 0.98| 3955     | 0.94|
| Magnolia insignis_MF990566.1         | 120850   | 0.98| 3942     | 0.94|
| Magnolia tripetala_NC024027.1        | 125593   | 0.94| 3611     | 0.86|
| Magnolia officinalis_NC020316.1      | 124347   | 0.93| 3534     | 0.84|
| Magnolia dealbata_NC023235.1         | 128285   | 0.93| 3485     | 0.83|
| Magnolia yunnanensis_NC024545.1      | 123790   | 0.93| 3481     | 0.83|
| Magnolia sinica_NC023241.1           | 123496   | 0.93| 3445     | 0.82|
| Magnolia kwangsiensis_HM775382.1     | 123473   | 0.93| 3479     | 0.83|
| Magnolia grandiflora_NC020318.1      | 123454   | 0.93| 3500     | 0.84|
| Magnolia pyramidata_NC023236.1       | 123322   | 0.93| 3462     | 0.83|
| Yulania acuminata_JX280391.1         | 122861   | 0.92| 3429     | 0.82|
| Michelia laevifolia_NC035956.1       | 122773   | 0.92| 3397     | 0.81|
| Yulania salicifolia_NC023240.1        | 122653   | 0.92| 3417     | 0.82|
| Michelia odora_NC023239.1            | 122171   | 0.92| 3349     | 0.80|
| Yulania diva?_NC023242.1             | 122135   | 0.92| 3350     | 0.80|
| Yulania puberula                      | 122115   | 0.92| 3356     | 0.80|
| Yulania cylindrica                   | 120078   | 0.92| 3344     | 0.80|
| Yulania biondii_KY085894.1           | 120009   | 0.92| 3339     | 0.80|
| Michelia cathcartii_NC023234.1       | 121998   | 0.92| 3322     | 0.79|
| Yulania shizheni                      | 121947   | 0.92| 3344     | 0.80|
| Yulania derudata_JN867577.1          | 121646   | 0.91| 3331     | 0.80|
| Yulania kobus_NC023237.1             | 121557   | 0.91| 3312     | 0.79|
| Yulania liliflora_JX280397.1         | 121203   | 0.91| 3359     | 0.80|
| Liriodendron tulipifera_DQ899947.1   | 105598   | 0.79| 2126     | 0.51|
| Liriodendron chinense_NC030504.1     | 105223   | 0.79| 2087     | 0.50|

Table 10. PHS and EVS of chloroplast genomes between Michelia odora and different species of Magnoliaceae Juss.

| Species name and cpDNA number of NCBI | PHL/17bp | PHS | EVL17bp | EVS |
|--------------------------------------|----------|-----|----------|-----|
| Michelia odora_NC023239.1            | 133199   | 1   | 4146     | 1   |
| Michelia laevifolia_NC035956.1       | 129813   | 0.97| 3902     | 0.94|
| Michelia cathcartii_NC023234.1       | 125770   | 0.94| 3607     | 0.87|
| Magnolia yunnanensis_NC024545.1      | 123016   | 0.92| 3411     | 0.82|
| Magnolia sinica_NC023241.1           | 122776   | 0.92| 3381     | 0.82|
| Magnolia dealbata_NC023235.1         | 122288   | 0.92| 3370     | 0.81|
| Yulania acuminata_JX280391.1         | 122268   | 0.92| 3373     | 0.81|
| Magnolia fordiana_MF990562.1         | 122169   | 0.92| 3347     | 0.81|
| Magnolia dandyi_NC037004.1           | 122155   | 0.92| 3345     | 0.81|
| Magnolia tripetala_NC024027.1        | 122090   | 0.92| 3341     | 0.81|
| Magnolia duclouxii_NC037002.1        | 122078   | 0.92| 3351     | 0.81|
| Yulania salicifolia_NC023240.1       | 122063   | 0.92| 3362     | 0.81|
| Magnolia glaucifolia_NC037003.1      | 122048   | 0.92| 3338     | 0.81|
| Magnolia insignis_MF990566.1         | 122030   | 0.92| 3343     | 0.81|
| Magnolia kwangsiensis_HM775382.1     | 122021   | 0.92| 3363     | 0.81|
| Magnolia pyramidata_NC023236.1       | 121652   | 0.91| 3323     | 0.80|
| Yulania diva?_NC023242.1             | 121577   | 0.91| 3314     | 0.80|
| Yulania puberula                      | 121405   | 0.91| 3308     | 0.80|
| Yulania cylindrica                   | 121381   | 0.91| 3303     | 0.80|
Species name and cpDNA number of NCBI | PHL/17bp | PHS | EVL/17bp | EVS
--- | --- | --- | --- | ---
Yulania biondii KY085894.1 | 121340 | 0.91 | 3280 | 0.79
Yulania shizhenii | 121311 | 0.91 | 3304 | 0.80
Magnolia grandiflora NC020318.1 | 121033 | 0.91 | 3297 | 0.80
Yulania denudata JN867577.1 | 121014 | 0.91 | 3294 | 0.79
Yulania kobus NC023237.1 | 120843 | 0.91 | 3245 | 0.78
Magnolia officinalis NC0203016.1 | 120742 | 0.91 | 3258 | 0.79
Yulania liliiflora JX280397.1 | 120661 | 0.91 | 3334 | 0.80
Liriodendron tulipifera DQ899947.1 | 104128 | 0.78 | 2034 | 0.49
Liriodendron chinense NC030504.1 | 104000 | 0.78 | 2010 | 0.48

Table 11. PHS and EVS of cpGenomes between Liriodendron tulipifera and different species of Magnoliaceae Juss.

Species name and cpDNA number of NCBI | PHL/17bp | PHS | EVL/17bp | EVS
--- | --- | --- | --- | ---
Liriodendron tulipifera DQ899947.1 | 133246 | 1 | 3618 | 1
Liriodendron chinense NC030504.1 | 123803 | 0.93 | 2995 | 0.83
Magnolia tripetala NC024027.1 | 105693 | 0.79 | 2153 | 0.60
Magnolia insignis MF990566.1 | 105662 | 0.79 | 2128 | 0.59
Magnolia duclouxii NC037002.1 | 105656 | 0.79 | 2133 | 0.59
Magnolia dealbata NC023235.1 | 105651 | 0.79 | 2131 | 0.59
Magnolia kwangsiensis HM775382.1 | 105629 | 0.79 | 2172 | 0.60
Magnolia fordiana MF990562.1 | 105597 | 0.79 | 2125 | 0.59
Magnolia dandyi NC037004.1 | 105550 | 0.79 | 2125 | 0.59
Magnolia glaucifolia NC037003.1 | 105471 | 0.79 | 2116 | 0.58
Magnolia yunnanensis NC024545.1 | 105464 | 0.79 | 2128 | 0.59
Magnolia sinica NC023241.1 | 105336 | 0.79 | 2117 | 0.59
Magnolia pyramidata NC023236.1 | 105308 | 0.79 | 2134 | 0.59
Magnolia officinalis NC020316.1 | 105033 | 0.79 | 2110 | 0.58
Yulania acuminata JX280391.1 | 104930 | 0.79 | 2089 | 0.58
Magnolia grandiflora NC023018.1 | 104838 | 0.79 | 2116 | 0.58
Michelia laevifolia NC035956.1 | 104757 | 0.79 | 2095 | 0.58
Yulania salicifolia NC023240.1 | 104741 | 0.79 | 2100 | 0.58
Yulania diva? NC023242.1 | 104483 | 0.78 | 2075 | 0.57
Michelia cathcartii NC023234.1 | 104322 | 0.78 | 2043 | 0.56
Magnolia biondii KY085894.1 | 104249 | 0.78 | 2061 | 0.57
Yulania cylindrica | 104133 | 0.78 | 2039 | 0.56
Michelia odorata NC023239.1 | 104130 | 0.78 | 2036 | 0.56
Yulania puberula | 104126 | 0.78 | 2038 | 0.56
Yulania shizhenii | 104103 | 0.78 | 2035 | 0.56
Yulania denudata JN867577.1 | 103967 | 0.78 | 2041 | 0.56
Yulania kobus NC023237.1 | 103946 | 0.78 | 2040 | 0.56
Yulania liliiflora JX280397.1 | 103412 | 0.78 | 2054 | 0.57

6. Evolutionary System of Magnoliaceae Juss

The taxonomical system of Magnoliaceae Juss. has always been more controversial. Dandy system [11] had the biggest impact, which included 12 genera: Manglietia Blum., Magnolia L., Talaula Juss., Aleimandra Dandy, Aromadendron Blum., Pachylarnax Dandy, Kmeria (Pierre) Dandy, Elmerrrillia Dandy, Michelia L., Paramichelia Hu, Tsongiodendron Chun and Liriodendron L.. Based on the system, Y. H. Law system [12] increased 3 genera: Manglietiastrum Law, Dugandiodendron G. Lozano-Contreras, Parakmeria Hu et Cheng. N. H. Xia system [13] increased 5 genera: Houpoea N. H. Xia & C. Y. Wu, Oyama (Nakai) N. H. Xia & C. Y. Wu, Lirianthe Spach, Woonyoungia Law, Yulania Spach. Most of these genera were not supported by the phylogeny, Bailon system [14] and Nooteboom system [15] only included 2 genera: Magnolia L. and Liriodendron L., which were adopted by the NCBI database.

Traditional taxonomical and phylogenetic system sometimes are inevitably partial and subjective [1]. To establish a scientific system, the PHS and EVS are analyzed based on the chloroplast complete genome of 28 species of Magnoliaceae using the types of 4 species respectively: Yulania denudata (Desr.) D. L. Fu, Magnolia fordiana (Oliver) Hu, Michelia odorata (Chun) Nooteboom & B. L. Chen, Liriodendron tulipifera L., and the results are shown in Table 8 to 11.

It can be seen from Table 8 to 11 that using the types of Yulania denudata (Desr.) D. L. Fu, Magnolia fordiana (Oliver) Hu, Michelia odorata (Chun) Nooteboom & B. L. Chen, Liriodendron tulipifera L., respectively, Magnoliaceae Juss. obviously include 4 natural genera: Yulania Spach, Magnolia L., Michelia L. and Liriodendron L., which all have the same boundaries: PHS(17bp)>0.93(inner genus) and PHS(17bp)<0.93(inter genera), and EVS(17bp)>0.83(inner genus) and EVS(17bp)<0.83(inter genera, except for Magnolia sinica (Y. W. Law) Nooteboom). For PHS being more easily calculated just need two samples, so
PHS(17bp)=0.93 can be regarded as the generic boundary of Magnoliaceae. Based on the boundary, it can be concluded that Manglietia Blum., Pachylarloss Dandy, Manglietiastrum Law, Parakmera Hu et Cheng, Houpoae N. H. Xia & C. Y. Wu, Woonyoungia Law, Alcinandra Dandy, and Tsongiodendron Chun are not supported by chloroplast complete genomic evolutionomy. By means of morphological evolutionomy, it can be basically concluded that Talauma Juss., Kmeria (Pierre) Dandy, Aromadendron Blum., Elmerrillia Dandy, Dugandiodendron G. Lozano-Contras, Oyama (Nakai) N. H. Xia & C. Y. Wu, Lirianthe Spach and Paramichelia Hu are not supported too.

According the evolutionary continuity principle, based on PHS and EVS of 28 species, the evolutionary system of Magnoliaceae Juss. can be established as Figure 2, which scientifically overcomes the partiality and subjectivity of traditional and phylogenic system.

**Figure 2.** Evolutionary system of genera of Magnoliaceae Juss. based on the chloroplast genomic and morphological evolutionomy.

The genera of Magnolia L., Michelia L. and Liriiodendron L. of Magnoliaceae Juss. were widely accepted by most of taxonomical system [2,8, 11-13, 15-19, 21-23], but the genus of Yulania Spach had been regarded as Magnolia L. by most botanical authorities [16-18]. As Yulania Spach was scientifically confirmed in 2001 [19], its species resources were also gradually identified [20-23].

### 7. Evolutionary Taxa of Yulania sect. Yulania Subsect. Cylindricae

**7.1. Yulania Subsect. Cylindricae** (Spongb.) D. L. Fu, Subsect. Comb. Nov., Figures 3 to 5

* Magnolia sect. *Cylindricae* S. A. Spongberg, in D. R. Hunt (ed.), *Magnolias & their allies*: 115. 1998. —*Yulania* sect. *Cylindricae* (Spong.) T. B. Zhao & Z. X. Chen, nom. illegit. (laps. cit.) in T. B. Zhao et al., Shijie Yulanshu Zhiwu Ziyuan Cylindrica 7.1. Yulania Subsect. Cylindricae (Spongb.) D. L. Fu, Yulania shizhenii D. L. Fu et F. W. Li, mainly distributed in Hubei, Anhui, Sichuan and other provinces of South China. The species of this subsection are the most primitive taxa of fruit plants, and plays an important role in the study of origin and evolution of fruit plants.

**7.2. Yulania Puberula** D. L. Fu, sp. Nov., Figure 3

Arbor decidua. Ramuli crassi, lenticellis rarioiribus rotundis leviter protuberantibus, hornotini purpureo-rubri pubescentes et puberuli nitidi, ramuli abbreviati 3~5-nodi, internodiis ca. 3 mm longis leviter crassis pallide brunneis sparse puberulis. Gammae foliiferae conoideae vel ovoideo-conoideae 0.5~1.2 cm longae et 0.2~0.4 cm diam. dense pallide adpresso-flavo-pubescentes. Alabastra solitaria, terminalia, ovoidea circa 2.0 cm longa et 1.0 cm diam. extus dense pallide adpresso-flavo-villosa. Folia alterna tenuior coriacea elliptica late oblanceolata vel oblongo-elliptica 6.5~10.0 cm longa et 2.0~3.5 cm lata apice acuminata vel late cuneata margin integrum supra viridia parte facile lateroscentia in sicco glabra nitida nervis et nervulis impressis rimosis in sicco subutus pallide viridea, dense puberula, pilis 1.5~2.5 dm longis, costis manifeste prominentibus dense puberulis, pilis usque ad 5.0 mm longis, nervis lateralis 10~15-jugis; petioli graciles 0.8~2.5 cm longi, dense puberuli, cicatriculis stipularum 2~3 mm longis interdum longitutine attingentibus 1/3 petiolorum partem aequantibus. Flores ante folia aperti, albi; pedicelli floriviriduli 0.8~1.2 cm longi et 0.7~0.8 diam. dense albi pubescentes vel villosi; bracteae 1, perulli-morphis; sepala (1~)3 alba carnosa linearia, petala 6(~8) alba carnosa spatulata vel spatulato-obovata, 7.0~10.0 cm longa et 3.5~6.0 cm lata extus costis rosalis basi vivido-purpureo-rubra. Stamina numerosa ca. 65 in queuo flore, 0.8~1.1 cm longa, pallide purpureo-rubra exstus costis rosalis, thecis lateribus longitudinali-dehiscentibus, connetivis aculeum mucronibus triangulis ca. 1.5 mm longis; filamentis ca. 2.5 mm longis rectangularibus pallide purpureo-rubris; gynoecum subsylliniumicruma. 1.6 cm longum, pistilla simplicia numerosa ca. 40~45 in queuo flore, glabra, ovaris pallide flavo-viridulis interdum pallide purpureo-rubris fasciatis protuberantibus costis purpureo-rubris, stylis et stigmatibus extus pallide purpureo-rubris. Folliceta breviter cylindrica purpureo-rubra ca. 5.0 cm longa et 2.8 cm diam. saepe curvata; semina depresso-globosa 0.7 mm longa et 0.7 cm lata. 

Hubei: D. L. Fu 2018032601 (Holotypus, hic designatus, CAF) branchlets with flower, were collected from Mountain Wudang at alt. about 970 m on Mar. 26, 2018, by D. L. Fu, and D. L. Fu 2017100801 (Paratypus, CAF), branchlets with fruit,
flower buds and leaves were collected from the same position on Oct. 08, 2017.

The chloroplast complete genome of this new species is mostly similar to Y. cylindrica (Wils.) D. L. Fu and PHS = 0.992.

The main typici-evolutionary characters including diagnostic differences and particularities of the new species are that the hornotini-branchlets reddish purple, leaves thin coriaceous, elliptic or oblanceolati-elliptic, reticulate veins depressed and rimous when dried; flower precocious, sepals 3 and tepals 6, stamens white and filaments wider than anthers.

**Typus:** D. L. Fu 200103161 (Holotypus, CAF), D. L. Fu 2017110501 (Epitypus, hic designatus, CAF). The types were collected from Chengdu city of Sichuan province of China and kept at Chinese Academy of Forestry (CAF).

This species is named for commemorating Li Shizhen, a great pharmacologist and botanist of ancient China.

**Distribution:** The species is mainly distributed in Hubei province of China.

The species is the most primitive fruit plants and will play an important role in researching the Evolutionomy of Magnoliaceae Juss. even that of Fructophyta D. L. Fu& H. Fu, but it is very rare in population, so the authors intensively proposed that the species should be protected as first level protection.
of China.

The species is an excellent ornamental tree species with the pure white flowers, open in early spring. Its flower buds into Chinese medicine, called Xinyi. As one of the most primitive taxa, it should be recommended for inclusion in the national first-level list of protected plants for its small number of populations and very important role in the origin and evolution of fruit plants.

7.4. Yulania Cylindrica (Wils.) D. L. Fu, Figure 5

J. Wuhan Bot. Res., 19(3): 198. 2001; Xia Nianhe et al., Flora of China vol. 7: 75. 2008; ——Magnolia cylindrica Wils. in J. Arnold Arbor. 8: 109. 1927. Typus: R. C. Ching 2949 (A, collected from Mountain Huang in Anhui province of China).

Yulania fragarigynandria T. B. Zhao, Z. X. Chen et H. T. Dai, in T. B. Zhao et al. Shijie Yulanshu Zhiwu Ziyuan yu Zaipei Liyong: 236-237. 2013. Type: 200504041(HEAC); T. B. Zhao et al. Shijie Yulanshu Zhiwu Zhongzhi Ziyuan Zhi: 78-79. 2013; T. B. Zhao et al., Henan Yulan Zaipei: 270-271. 2015.

Yulania gynophora T. B. Zhao, Z. X. Chen et J. Zhao, in T. B. Zhao et al. Shijie Yulanshu Zhiwu Ziyuan yu Zaipei Liyong: 288-289. 2013. Type: 200203131(HEAC); T. B. Zhao et al. Shijie Yulanshu Zhiwu Zhongzhi Ziyuan Zhi: 79-80. 2013; T. B. Zhao et al., Henan Yulan Zaipei: 269-270. 2015.

Yulania varians T. B. Zhao, Z. X. Chen et Z. F. Ren, in T. B. Zhao et al. Shijie Yulanshu Zhiwu Ziyuan yu Zaipei Liyong: 289-291. 2013. Type: 201303222(HEAC); in T. B. Zhao et al. Shijie Yulanshu Zhiwu Zhongzhi Ziyuan Zhi: 82-83. 2013; in T. B. Zhao et al., Henan Yulan Zaipei: 272-273. 2015.

Yulania anhueiensis T. B. Zhao, Z. X. Chen et J. Zhao, in T. B. Zhao et al. Shijie Yulanshu Zhiwu Ziyuan yu Zaipei Liyong: 302-303. 2013. Type: 200503301(HEAC); in T. B. Zhao et al. Shijie Yulanshu Zhiwu Zhongzhi Ziyuan Zhi: 78-79. 2013; in T. B. Zhao et al., Henan Yulan Zaipei: 268-269. 2015.

Magnolia glabrata auct. Non Law et R. Z. Zhou ined.: Y. H. Liu, Magnolias of China: pict.(top-left, p.61). 2004.

Yulania axilliflora auct. non(T. B. Zhao et al.) D. L. Fu: T. B. Zhao et al., Henan Yulan Zaipei: t.74(6). 2015.

The main typici-evolutionary characters: Fruit aggregates cylindric, often short and thick, and not curved, the follicles dehiscing by dorsal suture or not, but the apical portions falling away individually or in irregular masses leaving the seeds suspended on persistent central axes [17]. It can be clearly distinguished from other species of Yulania.

The species was described and illustrated as some new species such as Yulania fragarigynandria T. B. Zhao, Z. X. Chen et H. T. Dai [21-23], Yulania gynophora T. B. Zhao, Z. X. Chen et J. Zhao [21-23], Yulania varians T. B. Zhao, Z. X. Chen et Z. F. Ren [21-23] and Yulania anhueiensis T. B. Zhao, Z. X. Chen et J. Zhao [21-23], which all were synonyms of Yulania cylindrica (Wils.) D. L. Fu.

Distribution: The species is distributed in Anhui, Zhejiang, Jiangxi, Fujian, Hubei and Henan province of China, in broad-leaved forest at an altitude of 600~1600 m.

The species with white or whitish-purple flowers and red fruits, very beautiful, is an excellent ornamental tree species in urban and rural areas; Flower buds is used as Chinese medicine for "Xinyi", and is also an excellent spice plant resource.

8. Conclusion

Scientifically overcoming the limitation of Phylogeny sometimes being partial and subjective, typical algorithm for the genomic evolutionomy, is a scientifically new method and new tool to solve the puzzle of evolutionomy of fruit plants. Based on the results of chloroplast genomic analyses, it can be concluded that Fructophyta are originated from Ginkgoopsida of Gymnospermophyta, not from Cycadopsida thought by the euanthium-theory or Chlamydopspermopsida thought by the pseudoanthium-theory, which will create a new situation in the development of evolutionomy of Fructophyta D. L. Fu & H. Fu.

Among some representative species of Fructophyta, Ginkgo biloba has the closest relatively evolutionary relationship with Yulania puberula indicating that the new species is the relatively most primitive species of fruit plants. It is consistent with the research results of morphological evolutionomy, but it is not consistent with the current people's cognition. Therefore, it will certainly promote the research of re-understanding of the evolutionomy of fruit plants and promote the development of the evolutionomy of Fructophyta D. L. Fu & H. Fu.

Based on the results of evolutionomic analyses of chloroplast genomes and morphology, the evolutionary system of Magnoliaceae includes 4 natural genera: Yulania Spach, Magnolia L., Michelia L. and Liriodendron L., whose boundaries all are PHS(17bp)=0.93 (chloroplast complete genomes). This will create a new situation in the scientific classification of Magnoliaceae Juss. and will also promote the development of the evolutionomy of Fructophyta D. L. Fu & H. Fu.
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References

[1] D. L. Fu and H. Fu. “An evolutionary continuity principle for evolutionary system of organism divisions”. American Journal of Agriculture and Forestry, vol. 6, no. 3, pp. 60-64, 2018. DOI: 10.11648/j.ajaf.20180603.14.

[2] H. D. Zhang, Y. H. Huang, R. H. Miao, C. X. Ye, W. B. Liao, and J. H. Jin. “Systematics of Spermatophyta”. Beijing: Science Press. 72-626, 2004. [in Chinese]

[3] J. W. Wang. “Taxonomy of Spermophyta”. Beijing: Higher Education Press. 290-295, 1985. [in Chinese]

[4] J. Hutchinson. “The families of flowering plants”. Oxford: Oxford University Press. 1959.

[5] A. L. Takhtajan. “Outline of the classification of flowering plants (Magnoliophyta)”. Bot. Rev. vol. 46 no. 3, pp. 227-359, 1980.

[6] A. Cronquist. “An integrated system of classification of flowering plants”. New York: Columbia University Press, 1-1262, 1981.

[7] Z. Y. Wu, Y. C. Tang, A. M. Lu, Z. R. Chen, and D. Z. Li. “Synopsis of the new ‘polyphyletic-polychronous-polyporphic’ system of the angiosperms”. Acta Phytotaxonomica Sinica, vol. 40, no. 4, pp. 289-322, 2002.

[8] D. Z. Li (translator). “Plant systematic, A phylogenetic approach”. Beijing: Higher Education Press. 001-496, 2012. [in Chinese]

[9] N. Li, W. Huang, Q. Shi, Y. Zhang, and L. Song. “A CTAB-assisted hydrothermal synthesis of VO2(B) nanostructures for lithium-ion battery application”. Ceram. Int. vol. 39, pp. 6199-6206, 2013. DOI: 10.1016/j.ceramint.2013.01.039.

[10] M. Lohse, O. Drechsel, and R. Bock. “Organellar Genome DRAW (OGDRAW): A tool for the easy generation of high-quality custom graphical maps of plastid and mitochondrial genomes”. Curr. Genet. vol. 52, pp. 267–274, 2007.

[11] J. E. Dandy. Magnoliaceae. In: Hutchinson J (ed.). “The Genera of Flowering Plants, Dicotyledons”, Oxford, 50-57, 1964.

[12] Y. H. Liu. “A preliminary study on the taxonomy of the family Magnoliaceae”. Acta Phytotaxonomica Sinica, vol. 22, pp. 89-109, 1984.

[13] N. H. Xia. “A New classification System of the Family Magnoliaceae”. In: Xia N H, Zheng Q W, Xu F X, Wu Q G. Proceedings of the Second International Symposium on the Family Magnoliaceae. Wuhan: Huazhong University of Science & Technology Press. 12-38, 2009.

[14] H. Baillon. “Memoire sur la famille des Magnoliaceae”. Adansonia vol. 7, pp. 1-16, 1866.

[15] N. H. Xia, Y. H. Liu, H. P. Nooteboom. Magnoliaceae. In: Wu Z Y, P. H. Raven, Hong D Y. “Flora of China”, Beijing: Science Press & St. Louis, MO: Missouri Botanical Garden Press. vol. 7, pp. 71-77, 2008.

[16] D. J. Callaway. “The World of Magnolias”. Portland: Timer Press. 135-174, 1994.

[17] D. Hunt. “Magnolias and their allies”. Sherborne: International Dendrology Society and The Magnolia Society. 104-126, 1998.

[18] Y. H. Liu. “Magnolias of China”. Beijing: Science Press, 44-55, 2004.

[19] D. L. Fu. “Notes on Yulania Spach”. Journal of Wuhan Botanical Research, vol. 19, no. 3, pp. 191-198, 2001.

[20] D. L. Fu, D. L. Zhang, F. W. Li, J. H. Sun, and J. H. Ren. “Two New Species of Yulania Spach from Sichuan Province of China”. Bulletin of Botanical Research, vol. 30, no. 4, pp. 385-389, 2010.

[21] T. B. Zhao, G. H. Tian, D. L. Fu, and D. X. Zhao. “Shijie Yulanshu Zhiwu Ziyuan yu Zaipei Liyong”. Beijing: Science Press, 179-383, 2013. [in Chinese]

[22] T. B. Zhao, Z. F. Ren, and G. H. Tian. “Shijie Yulanshu Zhiwu Zhongzhi Ziyuan Zhi”. Zhengzhou: Yellow River Conservancy Press, 63-64, 2013. [in Chinese]

[23] T. B. Zhao, H. H. Song, G. H. Tian, and Z. X. Chen. “Henan Yulan Zaipei”. Zhengzhou: Yellow River Conservancy Press, 157 – 161, 2015. [in Chinese]