Diversity of *Cantharellus* (Cantharellales, Basidiomycota) in China with Description of Some New Species and New Records

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**Abstract:** *Cantharellus* is a well-known genus of edible mushrooms, belonging to the family Hydnaceae in the class Agaricomycetes. In this study, a phylogenetic overview of *Cantharellus* subg. *Cinnabarinus* and C. subg. *Parvocantharellus* in China is carried out with the description of four new species. Species description are based on morphological characters of basidiomata and phylogenetic analyses of multi-locus dataset of 28S + tef1 + rpl2. Among the new species, two species, *C. chrysanthus* and *C. sinocinnabarinus*, belong to C. subg. *Cinnabarinus* and two new species, *C. convexus* and *C. neopersicus*, belong to C. subg. *Parvocantharellus*. Species delimitation characters of the new taxa are compared with closely related species. In addition, three new records of *Cantharellus* are reported for China: *C. albivenosus* and *C. citrinus* of subg. *Cinnabarinus* and *C. koreanus* of subg. *Parvocantharellus*. A key to the species of subg. *Cinnabarinus* in China was provided.

**Keywords:** chanterelle; East Asia; new species; phylogeny; taxonomy

1. **Introduction**

*Cantharellus* Fr. was firstly described by Fries [1] based on the type species *Cantharellus cibarius* Fr. Most *Cantharellus* species are popular edible mushrooms, especially beloved in Europe. *Cantharellus* is an ectomycorrhizal genus, forming symbiosis with various plants, such as the trees of Fagaceae, Pinaceae, Betulaceae, Salicaceae, Juglandaceae, Leguminosae, etc. [2–8]. Species in *Cantharellus* are widely distributed and are especially rich in subtropical to tropical zones [9,10]. Up to now, about 300 species of *Cantharellus* have been reported worldwide [7]. However, the species diversity is poorly known in Asia in the past decades, and many specimens were named after European or North American species [6,11–13]. In recent years, some new species were reported from Asia based on the combination of morphological characters and DNA phylogenetic analyses [6,7,11–16]. Recent phylogenetic studies demonstrated that *Cantharellus* is monophyletic and forms a sister relationship with *Craterellus* Pers. [3,4,7]. Species in *Cantharellus* were divided into seven subgenera based on multi-locus phylogenetic analyses in Buyck et al. [3], and a subsequent study in Cao et al. [7]. *Cantharellus* subg. *Cinnabarinus* Buyck & V. Hofst., typified by *C. cinnabarinus* (Schwein.) Schwein. was introduced for a monophyletic assemblage of mostly quite small, yellow, orange, pink or red species, sometimes mixed with lilac-purple or brownish tones in the pileus center, strongly veined in the lamellate
hymenophore with principally thin-walled hyphal endings and abundant in clamp connections [3,17,18]. Species in subg. *Cinnabarinus* are widely distributed in Asia, Europe, North America, Australasia and Africa, and 16 species have been reported worldwide. In China, a large number of *Cantharellus* species have been reported, but only two species in the subg. *Cinnabarinus* were recorded, i.e., *C. cinnabarinus* and *C. phloginus*, by S.C. Shao & P.G. Liu. *Cantharellus cinnabarinus*, originally reported from North America, was recorded to be widely distributed in China [19–21]; *C. phloginus* was described as being from southwestern China [22].

In this study, a number of *Cantharellus* specimens were collected from China; further study proved that they represented eight distinct species, five of which belong to the subg. *Cinnabarinus* and three to the subg. *Parvocantharellus*. Four species are described below as new to science, which would make a contribution to understanding the species diversity of *Cantharellus* in China, and revealing the phylogenetic relationships of *Cantharellus* species.

2. Materials and Methods

2.1. Morphological Studies

Photographs of fresh basidiomata were taken in the field. Specimens were dried and deposited in the Fungarium of Guangdong Institute of Microbiology (GDGM). Descriptions of macro-morphological characters and habitats were obtained from photographs and field notes. The color codes followed Kornerup and Wanscher [23]. Microscopic observations were carried out on tissue sections stained with 5% aqueous KOH and 1% aqueous Congo red under a light microscope (Carl Zeiss Microscopy GmbH, Göttingen, Germany) with a magnification up to 1000×. For basidiospore descriptions, the notation (a–)b–c(–d) describes basidiospore dimensions, where the range b–c represented 90% or more of the measured values and ‘a’ and ‘d’ were the extreme values; $L_m$ and $W_m$ indicated the average length and width (±standard deviation) of the measured basidiospores, respectively; $Q$ referred to the length/width ratio of an individual basidiospore and $Q_m$ referred to the average $Q$ value of all basidiospores ± sample standard deviation. All line-drawings of microstructures were made based on rehydrated materials.

2.2. DNA Extraction, PCR Amplification and Sequencing

Genomic DNA was extracted from the voucher specimens using the Sangon Fungus Genomic DNA Extraction kit (Sangon Biotech Co., Ltd., Shanghai, China) according to the manufacturer’s instructions. Primer pairs LROR/LR7 [24], tef1F/tef1R and RPB2-5FCanth/RPB2-7cRCanth [3,25] were used to amplify the LSU, tef1 and rpb2 region, respectively. PCR reactions were performed in a total volume of 25 µL containing 0.5 µL template DNA, 11 µL sterile deionized water, 0.5 µL of each primer and 12.5 µL 2 × PCR mix [DreamTaq™ Green PCR Master Mix (2×), Fermentas, MA, USA]. Amplification reactions were performed in a Tprofessional Standard thermocycler (Biometra, Göttingen, Germany) under the following conditions: 95 °C for 4 min; then, 35 cycles of denaturation at 94 °C for 60 s, annealing at 53 °C (LSU)/50 °C (tef1)/52 °C (rpb2) for 60 s and extension at 72 °C for 60 s; with a final extension at 72 °C for 8 min. The PCR products were electrophoresed on 1% agarose gels and then send for sequencing on an ABI Prism® 3730 Genetic Analyzer (PE Applied Biosystems, Foster, CA, USA) at the Beijing Genomic Institute (BGI) using the same PCR primers. The raw sequences were assembled and checked with SeqMan implemented in Lasergene v7.1 (DNASTAR Inc., Madison, WI, USA). The newly generated sequences in this study were submitted to GenBank.

2.3. Phylogenetic Analyses

Sequences generated in this study and those downloaded from GenBank were combined and used for phylogenetic reconstruction. Detailed information of specimens included in this study was given in Table 1. Three sequence matrices, i.e., nrLSU, tef1 and rpb2, were aligned separately with software MAFFT v6.853 using the E-INS-i strategy [26]
and then manually adjusted in MEGA 6 [27]. The ambiguous aligned regions and introns of the two protein-coding genes of *tef1* and *rpb2* were retained in the final analyses. Maximum Likelihood (ML) analyses were inferred using RAxML v7.2.6 [28], and all parameters were kept as defaults except for choosing GTR+GAMMAI as the model; statistical supports were obtained using rapid non-parametric bootstrapping with 1000 replicates. Bayesian Inference (BI) phylogenies were inferred using MrBayes 3.2.6 [29]; the best models of the multi-locus datasets were searched via the PartitionFinder 2 [30] for each locus, i.e., K80 + I + G, SYM + I + G and SYM + I + G for 28S, *tef1* and *rpb2*, respectively. BI analysis using 4 chains were conducted by setting generations to 20 million and stoprule command with the value of stopval set to 0.01; trees were sampled every 1000 generations, the first 25% generations were discarded as burn-in and posterior probabilities (PP) were then calculated from the posterior distribution of the retained Bayesian trees. *Cantharellus cibarius* Fr. was selected as the outgroup based on recent studies [3,13]. The phylogenetic trees were visualized using FigTree v1.4.23.

Table 1. Specimen information used in this study. Sequences newly generated in this study are in bold; HT, NT and ET refer to holotype, neotype and epitype, respectively.

| Taxa                     | Voucher          | Locality         | GenBank Accession No.               | Reference                  |
|--------------------------|------------------|------------------|-------------------------------------|----------------------------|
|                          |                  |                  | LSU | *tef1* | *rpb2* |                |
| *Cantharellus afrocinibarius* | BB 96.236        | Zambia           |     | KF294669 | JX192994 | KF294747 | [3]          |
| *C. afrocinibarius*       | BB 96.235 (HT)   | Zambia           |     | KF294668 | JX192993 | KF294746 | [3]          |
| *C. albocenosus*          | 1690 (HT)        | South Korean     | –   | –       | KY271942 | –       | [11]         |
| *C. albocenosus*          | 1713             | South Korean     | –   | –       | MW124387 | –       | [11]         |
| *C. albocenosus*          | GDGM85853        | China            | OM978952 | ON119062 | ON119006 | Present study |
| *C. albocenosus*          | GDGM85846        | China            | OM978950 | ON119060 | ON119004 | Present study |
| *C. albocenosus*          | GDGM85142        | China            | OM978949 | ON119059 | ON229082 | Present study |
| *C. albocenosus*          | HMAS279296       | China            | OM978948 | ON119066 | ON119010 | Present study |
| *C. albocenosus*          | HMAS279284       | China            | ON212414 | ON119064 | ON119008 | Present study |
| *C. albocenosus*          | HMAS279292       | China            | ON212412 | ON119065 | ON119009 | Present study |
| *C. albocenosus*          | HMAS279262       | China            | OM978947 | ON119063 | ON119007 | Present study |
| *C. albocenosus*          | GDGM85852        | China            | OM978951 | ON119061 | ON119005 | Present study |
| *C. albus*                | HKAS107045 (HT)  | China            | MT782540 | MT766015 | MT766012 | [12]         |
| *C. albus*                | GDGM61399        | China            | MZ605074 | MZ613977 | MZ614022 | [13]         |
| *C. albus*                | GDGM81064        | China            | MZ605073 | MZ613976 | MZ614021 | [13]         |
| *C. appalachiensis*       | GRSM77088        | USA              | DQ898690 | –       | DQ898748 | [31]         |
| *C. appalachiensis*       | BB 07.123        | USA              | KF294635 | GQ914979 | KF294711 | [3]          |
| *C. aurantinus*           | GDGM46278 (HT)   | China            | MZ766517 | MZ766560 | –       | [13]         |
| *C. aurantinus*           | GDGM46279        | China            | MZ766518 | MZ766561 | MZ766571 | [13]         |
| *C. aurantinus*           | GDGM81899        | China            | MZ766520 | MZ766563 | MZ766573 | [13]         |
| *C. aurantinus*           | GDGM84974        | China            | MZ766521 | MZ766564 | MZ766572 | [13]         |
| *C. austrosinensis*       | GDGM81303        | China            | MZ605082 | MZ613986 | MZ614029 | [13]         |
| *C. austrosinensis*       | GDGM81249 (HT)   | China            | MZ605082 | MZ613983 | MZ614027 | [13]         |
| *C. austrosinensis*       | GDGM80616        | China            | MZ605081 | MZ613982 | MZ614026 | [13]         |
| *C. austrosinensis*       | GDGM81381        | China            | MZ605086 | MZ613988 | MZ614031 | [13]         |
| *C. austrosinensis*       | GDGM81379        | China            | MZ605085 | MZ613987 | MZ614030 | [13]         |
| *C. austrosinensis*       | GDGM81985        | China            | MZ605087 | MZ613989 | MZ614032 | [13]         |
| *C. chrysanthus*          | GDGM45166        | China            | OM978959 | ON119074 | ON119011 | Present study |
| *C. chrysanthus*          | GDGM45937        | China            | OM978960 | ON119075 | ON119012 | Present study |
| *C. chrysanthus*          | GDGM85298        | China            | OM978975 | ON119089 | ON119025 | Present study |
| *C. chrysanthus*          | GDGM85305        | China            | OM978976 | ON119090 | ON119026 | Present study |
| *C. chrysanthus*          | GDGM53485        | China            | OM978962 | ON119077 | ON119014 | Present study |
| *C. chrysanthus*          | GDGM80220 (HT)   | China            | OM978970 | ON119083 | ON119019 | Present study |
| *C. chrysanthus*          | GDGM82311        | China            | OM978973 | ON119087 | ON119023 | Present study |
| *C. chrysanthus*          | GDGM82316        | China            | OM978974 | ON119088 | ON119024 | Present study |
| *C. chrysanthus*          | GDGM80436        | China            | OM978971 | ON119084 | ON119020 | Present study |
| Taxa      | Voucher | Locality | GenBank Accession No. | Reference            |
|-----------|---------|----------|-----------------------|----------------------|
|           |         |          | LSU  tef1  rpb2        |                      |
| C. chrysanthus | GDGM80202 | China    | OM978965 ON119080 ON119016 | Present study        |
| C. chrysanthus | GDGM80204 | China    | OM978966 ON119081 ON119017 | Present study        |
| C. chrysanthus | HMAS279434 | China    | ON212413 ON119091 ON229079 | Present study        |
| C. chrysanthus | GDGM80438 | China    | – ON119085 ON119021 | Present study        |
| C. chrysanthus | GDGM82473 | China    | OM978972 ON119086 ON119022 | Present study        |
| C. chrysanthus | GDGM77035 | China    | OM978964 ON119079 ON229081 | Present study        |
| C. chrysanthus | GDGM60524 | China    | OM978963 ON119078 ON119015 | Present study        |
| C. chrysanthus | GDGM80217 | China    | OM978969 ON119082 ON119018 | Present study        |
| C. chrysanthus | GDGM49628 | China    | OM978961 ON119076 ON119013 | Present study        |
| C. chrysanthus | GDGM87950 | China    | OM978968 – ON119027 | Present study        |
| C. chrysanthus | GDGM87951 | China    | OM978967 – ON119028 | Present study        |
| C. cibarius | GE 07.025 | France   | KF294658 GQ914949 KF294736 | [3]                  |
| C. cibarius | BB 07.300 | Slovakia | KF294641 GQ914950 KF294718 | [3]                  |
| C. cinnabarinus | BB 04.263 | USA – | – GQ914983 | [32]                  |
| C. cinnabarinus | BB 07.053 | USA | KF294630 GQ914984 KF294705 | [32]                  |
| C. cinnabarinus | BB 07.001 | USA | KF294624 GQ914985 KF294698 | [32]                  |
| C. citrinus  | 1691 (HT) | South Korean – | MW124385 – | [16]                  |
| C. citrinus  | 1715 | South Korean – | MW124388 – | [16]                  |
| C. citrinus  | 1710 | South Korean – | MW124386 – | [16]                  |
| C. coccolobae | 1064_RC. 14_24 | Guadeloupe | KX857088 KX857020 KX856992 | [33]                  |
| C. coccolobae | 1065_RC. 11_25 (HT) | Guadeloupe | KX857089 KX857021 KX856993 | [33]                  |
| C. congolensis | 1645/BB16.044 | Saharan Africa | KX857102 KX857075 KX857006 | [33]                  |
| C. congolensis | 1676/BB16.123 | Saharan Africa | KX857106 KX857078 KX857010 | [33]                  |
| C. aff. congolensis | BB 06.176 | Madagascar | KF294606 – | KF294680 | [3]                  |
| C. aff. congolensis | BB 06.197 | Madagascar | KF294608 – | KF294683 | [3]                  |
| C. convexus  | GDGM54841 | China | OM978940 ON119052 ON119036 | Present study        |
| C. convexus  | GDGM70307 (HT) | China | OM978941 ON119053 ON119037 | Present study        |
| C. corallinus | 1083_JJ_MO_CANT_2 | USA – | KX857031 – | [34]                  |
| C. corallinus | 1086_JJ_MO_CANT_5 | USA – | KX857034 – | [34]                  |
| C. corallinus | FLAS_F_61106 | USA – | MK045368 – | [34]                  |
| C. curvatus | BRNM:825497 (HT) | South Korea | MW124390 | [16]                  |
| C. cyphelloides | TNS F-61721 (HT) | Japan | NG059027 | – | [35]                  |
| C. decolorans | BB 08.278 (HT) | Madagascar | KF294654 GQ914968 KF294731 | [3]                  |
| C. fistulosus | DT_43 | Tanzania | JQ976965 JX12997 | – | [3]                  |
| C. friesi | AH44798 | Spain | KX828752 KX828753 | [36]                  |
| C. friesi | VDKO 1165 | Africa | – KX834408 KX881922 | [3]                  |
| C. galbanus | GDGM86249 (HT) | China | ZM766516 MZ766568 MZ766577 | [13]                  |
| C. garnierii | BB 09.024 | New Caledonia | KX857085 KX857017 KX856989 | [34]                  |
| C. garnierii | BB 09.283 | New Caledonia | KX857087 KX857019 KX856991 | [34]                  |
| C. garnierii | BB 09.033 | New Caledonia | KX857086 KX857018 KX856990 | [34]                  |
| C. garnierii | RF33 | New Caledonia | AV392768 – | – | [37]                  |
| C. garnierii | RF32 | New Caledonia | AV392767 – | – | [37]                  |
| C. koreanus | 1697 | South Korea – | KY271940 – | – | [11]                  |
| C. koreanus | 1689 (HT) | South Korea – | KY271941 | – | [11]                  |
| C. koreanus | GDGM85306 | China | OM978978 ON119093 ON229077 | Present study        |
| C. koreanus | GDGM79233 | China | OM978977 ON119092 ON229078 | Present study        |
| C. koreanus | 1693 | South Korea – | – | – | Unpublished            |
| C. koreanus | 1694 | South Korea – | – | – | Unpublished            |
### Table 1. Cont.

| Taxa                  | Voucher          | Locality         | LSU Accession No. | tef1 Accession No. | rpb2 Accession No. | Reference                        |
|-----------------------|------------------|------------------|-------------------|--------------------|---------------------|----------------------------------|
| C. koreanus           | 1696             | South Korea      | –                 | –                  | –                   | Unpublished                     |
| C. luteolus           | GDGM60393 (HT)   | China            | ZM766515          | MZ766566           | MZ766575            | [13]                             |
| C. luteolus           | GDGM86247        | China            | MZ766513          | MZ766567           | MZ766576            | [13]                             |
| C. luteolus           | GDGM44258        | China            | ZM766514          | MZ766566           | MZ766570            | [13]                             |
| C. luteovirens        | GDGM81079        | China            | MZ605092          | MZ613994           | MZ614036            | [13]                             |
| C. luteovirens        | GDGM80672 (HT)   | China            | MZ605090          | MZ613992           | MZ614035            | [13]                             |
| C. luteovirens        | GDGM80680        | China            | MZ605091          | MZ613993           | –                   | [13]                             |
| C. minioalbus         | GDGM78910        | China            | MZ605098          | MZ613999           | MZ614043            | [13]                             |
| C. minioalbus         | GDGM78901 (HT)   | China            | MZ605097          | MZ613998           | MZ614042            | [13]                             |
| C. minor              | BB 07.057        | USA              | KF294632          | JX192979           | KF294707            | [3]                              |
| C. minor              | BB 07.002        | USA              | KF294625          | JX192978           | KF294699            | [3]                              |
| C. neopersicinus      | GDGM85145-1      | China            | OM978942          | ON119054           | ON119039            | Present study                    |
| C. neopersicinus      | GDGM85145-2      | China            | OM978945          | ON119055           | ON119040            | Present study                    |
| C. neopersicinus      | GDGM85145-3      | China            | OM978946          | ON119056           | ON119041            | Present study                    |
| C. neopersicinus      | GDGM87366-1 (HT) | China            | OM978943          | ON119057           | ON119042            | Present study                    |
| C. neopersicinus      | GDGM87366-2      | China            | OM978944          | ON119058           | ON119043            | Present study                    |
| C. phloginus          | GDGM79007-1      | China            | OM978979          | ON119094           | ON119044            | Present study                    |
| C. phloginus          | GDGM79007-2      | China            | OM978980          | ON119095           | ON119045            | Present study                    |
| C. phloginus          | SSC99 (HT)       | China            | –                 | KF801096           | –                   | [22]                             |
| C. phloginus          | SSC98            | China            | –                 | KF801095           | –                   | [22]                             |
| C. phloginus          | Yuan14468        | China            | –                 | MW999424           | –                   | [7]                              |
| C. phloginus          | Yuan14490        | China            | –                 | MW999425           | –                   | [7]                              |
| C. phloginus          | GDGM825314       | China            | –                 | ON119096           | –                   | Present study                    |
| C. pseudoaminimus     | JV 00.665        | Portugal         | KF294657          | JX192991           | KF294735            | [3,10]                           |
| C. romagnesianus      | AH44218          | Spain            | KX828807          | KX828836           | KX828757            | [36]                             |
| C. roseofingerorum    | AH44789          | Georgia          | KX828812          | KX828839           | KX828760            | [36]                             |
| C. sinocinnabarinus   | GDGM83229        | China            | OM978983          | ON119098           | ON119047            | Present study                    |
| C. sinocinnabarinus   | GDGM83238        | China            | OM978985          | ON119101           | ON119051            | Present study                    |
| C. sinocinnabarinus   | GDGM83023        | China            | OM978981          | ON119097           | ON119050            | Present study                    |
| C. sinocinnabarinus   | GDGM83232        | China            | –                 | ON119100           | ON119049            | Present study                    |
| C. sinocinnabarinus   | GDGM83027        | China            | OM978982          | –                 | ON119046            | Present study                    |
| C. sinocinnabarinus   | GDGM83230 (HT)   | China            | OM978984          | ON119099           | ON119048            | Present study                    |
| C. sinocinnabarinus   | HKAS58243        | China            | JP906727          | –                 | –                   | [20]                             |
| C. sinominor          | GDGM80788        | China            | MZ605105          | MZ614004           | MZ614048            | [13]                             |
| C. sinominor          | GDGM80842 (HT)   | China            | MZ605107          | MZ614006           | MZ614050            | [13]                             |
| C. sinominor          | GDGM80885        | China            | MZ605108          | MZ614007           | MZ614051            | [13]                             |
| C. aff. subcyanoxanthus | BB 98.014       | Tanzania         | KF294615          | JX192973           | KF294689            | [3]                              |
| C. tabernensis        | BB 07.119        | USA              | KF294634          | GQ194976           | KF294709            | [3]                              |
| C. tabernensis        | BB 07.056 (ET)   | USA              | KF294631          | GQ194974           | KF294706            | [3,38]                           |
| C. texensis           | 341/O7.120       | USA              | JN940601          | GQ194987           | KF294710            | [3]                              |
| C. texensis           | BB 07.018        | USA              | KF294626          | GQ194988           | KF294701            | [3]                              |
| C. xanthocyaneus      | 1751             | Congo            | MT006309          | MT002277           | –                   | [39]                             |
| C. xanthocyaneus      | Congo            | Congo            | MT006310          | MT002278           | –                   | [39]                             |
| C. zangii             | GDGM82389        | China            | MZ605110          | MZ614009           | MZ614053            | [13]                             |
| C. zangii             | GDGM82393        | China            | MZ605111          | MZ614010           | MZ614054            | [13]                             |
| C. zangii             | GDGM82374        | China            | MZ605109          | MZ614008           | MZ614052            | [13]                             |

### 3. Results

#### 3.1. Molecular Phylogeny

For phylogenetic analyses, a total of 152 sequences were newly produced in this study, containing 49 nrLSU, 51 tef1 and 52 rpb2, and 185 reliable sequences were downloaded from the GenBank database based on previous studies [3,13]. The combined dataset (LSU + tef1 + rpb2) contained 2892 characters (1311, 707 and 874 for LSU, tef1 and rpb2, respectively), of which 2013 were conserved and 708 were parsimony-informative. ML
and BI analyses of the concatenated data set resulted in almost identical topologies, and no strongly-supported conflicts between ML and BI analyses were discovered; thus, only the tree inferred from ML analysis was displayed (Figure 1). Our phylogenetic analyses indicated that members of C. subg. Cinnabarinus formed a highly supported monophyletic group (MLB/BPP = 100%/1.0). Five well-supported clades in the subg. Cinnabarinus were identified based on samples newly collected from China, including two new species, two species newly recorded in China and a known species in China. Besides, three well-supported clades in the subg. Parvocantharellus were firstly discovered in China, containing two new species and a newly recorded species from China.

Figure 1. Cont.
Figure 1. Phylogenetic tree of representative species of *Cantharellus* inferred from LSU-*tef1*-rpb2 dataset by means of both ML and BI methods. *Cantharellus cibarius* Fr. served as outgroup. Bootstrap Supports (BS > 50%) and Bayesian Posterior Probabilities (BPP > 0.90) are shown on the supported branches. Bold names represent new species.

3.2. Taxonomy

3.2.1. *Cantharellus* subgen. *Cinnabarinus* Buyck & V. Hofst.

*Cantharellus chrysanthus* Ming Zhang, C.Q. Wang & T.H. Li sp. nov.; Figures 2 and 3. MycoBank: MB843657.

GenBank: OM978970 for LSU, ON119083 for *tef1* and ON119019 for *rpb2*.

Etymology—refers to the color of pileus similar to the yellow chrysanthemum flower.

Diagnosis—This species is characterized by its orange to orange-yellow pileus, pinkish white to orange white hymenophore, thin-walled pileipellis terminal hyphae, broadly ellipsoid basidiospores (7.5–9 × 5–6.5 µm) and long basidia up to 100 µm.

Type—CHINA. Guangdong Province, Shaoguan City, Ruyuan town, Nanling National Natural Reserve, alt. 500 m, 10 June 2020, Ming Zhang (GDGM80220).
3.2. Taxonomy

3.2.1. Cantharellus subgen. Cinnabarinus Buyck & V. Hofst.

*Cantharellus chrysanthus* Ming Zhang, C.O. Wang & T.H. Li sp. nov.; Figures 2 and 3

MycoBank: MB843657. GenBank: OM978970 for LSU, ON119083 for *tef1* and ON119019 for *rpb2*.

**Etymology**—refers to the color of pileus similar to the yellow chrysanthemum flower.

**Diagnosis**—This species is characterized by its orange to orange-yellow pileus, pinkish white to orange white hymenophore, thin-walled pileipellis terminal hyphae, broadly ellipsoid basidiospores (7.5–9 × 5–6.5 μm) and long basidia up to 100 μm.

**Type**—CHINA. Guangdong Province, Shaoguan City, Ruyuan town, Nanling National Natural Reserve, alt. 500 m, 10 June 2020, Ming Zhang (GDGM80220).

**Figure 2.** Basidiomata of *Cantharellus chrysanthus*. (a,b) GDGM80220, holotype. (c) GDGM60524. (d) GDGM80438. (e) GDGM82516. (f) GDGM80217. (g) GDGM49628. (h) GDGM80436. (i) GDGM60334. (j) GDGM80202. (k) GDGM45937. (l) GDGM85298. (m) GDGM82473. Bars = 2 cm.

Basidiomata small-sized. Pileus 20–60 mm broad, convex, with involute margin when young, then gradually to nearly applanate or broadly infundibuliform with depressed center and inflexed to straight, irregularly undulate or slightly cracked at maturity; surface dry or hygrophanous, glabrous or finely subtomentose, orange (5A7–6A7) to deep orange (5A8–6A8) when young, slightly fading to orange yellow to yellow (3A7–4A7) when mature. Context yellowish white to orange white (4A2–6A2), 1–2 mm thick in the center of the pileus, sharply attenuate towards margin, unchanging when exposed. Hymenophore decurrent, subdistant, composed of bifurcate, 2–3 mm high venose folds, particularly towards pileus margin, pinkish white (7A2–10A2), but in some specimens yellowish white to orange white, unchanging when bruised. Stipe 20–60 × 3–14 mm, central, cylindrical or slightly tapering towards base, solid, glabrous or finely pubescent, concolorous with pileus or paler, unchanging when handled. Odor fruity and pleasant. Taste mild.
Basidiospores 7.5–9 × 5–6.5 µm, $L_m \times W_m = 8.45(\pm0.47) \times 5.98(\pm0.42)$ µm, $Q = (1.25) 1.28–1.6(1.64)$, $Q_m = 1.42 \pm 0.1$; broadly elliptical to subglobose, smooth, guttulate, thin-walled. Basidia 55–100 × 7–11 µm, 2–6-spored, narrowly clavate, colorless to hyaline in KOH; sterigmata 6–10 µm long. Pileipellis a cutis with long, repent and occasionally interwoven hyphae, subcylindrical cells that are 6–12 µm wide, thin-walled. Stipitipellis a cutis of cylindrical, parallel hyphae, 3–8 µm wide. Clamp connections abundant in all tissues.

Habitat and distribution—Solitary or scattered under Fagaceae trees mixed with other broadleaf trees in subtropical forests. Known from southern and southwestern China.

Additional specimen examined—China. Guangdong Province, Shaoguan City, Ruyuan town, Nanling National Natural Reserve, alt. 500 m, 7 June 2017, Ming Zhang (GDGM49628); same location, alt. 500 m, 21 July 2017, Ming Zhang (GDGM60524); same location, alt. 500 m, 9 June 2020, Ming Zhang (GDGM80436, GDGM80438); same location, alt. 500 m, 10 June 2020, Ming Zhang (GDGM80202, GDGM80204, GDGM80217, GDGM80220); Huizhou city, Xiangtoushan National Natural Reserve, alt. 550 m, 17 May 2016, Ting Li (GDGM45937); Hunan Province, Rucheng town, Jiulongjiang National Forest Park, alt. 300 m, 4 September 2016, Ming Zhang (GDGM53485); Zhejiang province, Jinhua city, Wuyi
Notes—Cantharellus chrysanthus is different from other Cantharellus species by the combined features of the orange to orange-yellow pileus, the pinkish white to orange white hymenophore, the thin-walled terminal hyphae of pileipellis, the broadly ellipsoid basidiospores (7.5–9.0 × 5.0–6.5 μm) and the long basidia up to 100 μm.

Phylogenetically, C. chrysanthus is related to C. albovenosus and C. phloginus in the analyses of the multi-locus datasets. However, C. albovenosus differs in its orange to reddish orange pileus with tomentum or fibrilla, white to orange and better-developed hymenophore, orange to reddish orange stipe, smaller basidiospores (7.0–8.5 × 5.0–6.0 μm) and shorter basidia (50–63 × 7–9 μm) [11]; Cantharellus phloginus, reported from southwest China, differs in its pastel red to pastel pink pileus and stipe, pale yellow to light yellow hymenophore, larger basidiospores [6.8–9.5 (–12) × 5.0–7.0 μm] and shorter basidia (60–95 × 8–10 μm) [22].

Cantharellus sinocinnabarinus Ming Zhang, S.C. Shao & T.H. Li sp. nov.; Figures 4 and 5.

Figure 4. Basidiomata of Cantharellus sinocinnabarinus. (a,c) GDGM83230. (b) GDGM83232. (d) GDGM83229. (e) GDGM832296. (f) GDGM83027. (g) GDGM83238. (h) HKAS58243. Bars = 2 cm.
Figure 4. Basidiomata of *Cantharellus sinocinnabarinus*. (a,c) GDGM83230. (b) GDGM83232. (d) GDGM83229. (e) GDGM832296. (f) GDGM83027. (g) GDGM83238. (h) HKAS58243. Bars = 2 cm.

Figure 5. *Cantharellus sinocinnabarinus*. (a) Basidiospores. (b) Basidia, basidiola and elements of the subhymenium. (c) Pileipellis. Bars: (a,b) = 10 μm; (c) = 20 μm.

MycoBank: MB843658.
GenBank: OM978984 for LSU, ON119099 for *tef1* and ON119048 for *rpb2*. 
Etymology—Refers to the species distributed in China and is similar to *C. cinnabarinus* in morphology.

Diagnosis—This species is characterized by its small basidiomata, reddish orange to yellowish red pileus covered with white minute fibrils, yellowish orange to orange hymenophore and elongate elliptical basidiospores measuring (6.5–) 7–8 (9) × (4.5) 5–6 μm.

Type—China. Yunnan Province, Lijiang City, Yulong County, Jiuhe Village, 1 September 2020, alt. 2400 m, Ming Zhang (GDGM83230).

Basidiomata small-sized. Pileus 5–15 mm broad, applanate with a depressed center, not perforate; margin slightly incurved when young, applanate to reflexed with age; surface dry, orange, reddish orange to yellowish red (6A7–8A7), locally with white minute fibrils. Context thin, 0.5–1.5 mm thick, fleshy to fibrous, yellowish orange to reddish orange, unchanging when bruised. Hymenophore subdecurrent, with a clearly delimitation from stipe surface; lamellate ridges subdistant to close, well-developed, 1–2 mm high, appropriately bifurcate, with low interconnected low venose folds, particularly at pileus margin, yellowish orange to orange (4A7–6A7), unchanging when bruised. Stipe 10–15 mm long, 1–2.5 mm thick, subcylindrical, slightly tapering downward, glabrous or with obscure white minute fibrils, hollow, concolorous with pileus. Odor pleasant.

Basidiospores (100/4/4) (6.5) 7–8 (9) × (4.5) 5–6 μm, $L_m$ × $W_m = 7.47(±0.5) \times 5.21(±0.39) \mu m$, $Q = (1.25)1.27–1.6(1.67)$, $Q_m = 1.43 \pm 0.09$; elliptical to elongate elliptical. Basidia 50–75 × 10–12 μm, clavate, with 4–8 sterigmata. Pileipellis a cutis, composed of procumbent hyphae; hyphae 4–13 μm in diam., colorless, thin-walled. Hymenophoral trama composed of cylindrical hyphae 5–10 μm in diam. Stipitipellis a cutis, composed of procumbent, branched hyphae; hyphae 4–12 μm in diam., mostly 7 μm in diam. Cystidia absent. Clamp connections common.

Habitat and distribution—Gregarious on soil in subalpine mixed forest dominated by *Cyclobalanopsis delavayi* (Franch.) Schott. and *Pinus yunnanensis* Franch. Currently known from southwest China.

Additional specimens examined—China. Yunnan Province, Jianchuan County, Qianshi Mountain, 7 September 2009, alt. 2491 m, Yu23 (HKAS58243); Lijiang City, Yulong County, Jiuhe Village, 1 September 2020, alt. 2400 m, Ming Zhang (GDGM83229, GDGM83232, GDGM83027), Li-Qiang Wu (GDGM83238).

Notes—*Cantharellus sinocinnabarinus* can be easily recognized in the field by its small reddish orange basidiomata. Morphologically, *C. sinocinnabarinus* is similar to *C. cinnabarinus*, *C. persicinus* R.H. Petersen and *C. texensis*. However, the latter three species were all originally reported from North America; *C. cinnabarinus* and *C. persicinus* differ in their larger basidiomata (pileus up to 40 mm), thicker-walled hyphae of pileipellis terminal cells, and different sizes of basidiospores (6.7–7.57 × 3.82–4.68 μm for *C. cinnabarinus*, and 10.2–11.9 × 6.3–7.2 μm for *C. persicinus*) [32]; *C. texensis* differs in its robust basidiomata and longer but narrower basidiospores (8–8.95 × 3.7–4.3 μm), with a larger Q value (1.8–2.2) [32].

Shao et al. [20] has described a specimen (HKAS58243) under the name *C. cinnabarinus* on the basis of the LSU sequence, which is geographically close to *C. sinocinnabarinus* in southwest China. In this study, the specimen (HKAS58243) was re-examined; the morphological features and molecular phylogenetic analyses all demonstrated that it is actually *C. sinocinnabarinus*.

In the multi-locus phylogenetic trees, specimens of *C. sinocinnabarinus* formed a well-supported independent terminal branch (BS = 100%, BPP = 1.0) in the subg. *Cinnabarinus*, and are closely related to *C. cinnabarinus*. However, they can be easily distinguished by the morphological features and large genetic distance.

*Cantharellus albovenosus* Buyck, Antonin & Ryoo, in Antonin, Hofstetter, Ryoo, Ka and Buyck, Mycol. Progr. 16(8): 757 (2017); Figures 6 and 7.

Basidiomata small-sized. Pileus 20–55 mm broad, convex at first, then broad applanate with a depressed centre, subinfundibuliform when mature or old; margin inflexed to straight when young, then undulate; surface tomentose when young, then glabrescent and...
radially (innately) fibrillose to finely striate and rugulose, orange, deep orange to reddish orange (5A6–7A6, 5A8–7A8), then pallescent to light orange at margin. Hymenophore decurrent, with a clearly delimitation from stipe surface; lamellate ridges, subdistant to distant, relatively well-developed, 1–1.5 mm high, appropriately bifurcate and interconnected with low veined folds, particularly towards pileus margin, white to orange white (5A2–6A2), unchanging when bruised. Stipe 25–50 × 2.5–9 mm, cylindrical and slightly clavate to bulbose at base, finely tomentose when young, then glabrous or with finely longitudinally fibrillose, concolorous with pileus, orange to reddish orange, sometimes paler to light orange in some specimens. Context white, orangish under pileipellis, solid, becoming hollow-fibrous in stipe. Odor spicy. Taste mild.

Basidiospores 7–8.5 × 5–6 μm, L₀ × W₀ = 7.9(±0.48) × 5.5(±0.34) μm, Q₀ = (1.33)1.4–1.5(1.54), Q₀m = 1.44 ± 0.05; ellipsoid to subglobose, thin-walled, sometimes with granulose contents. Basidia 48–63 × 7–9 μm, 2–6-spored, clavate, sometimes subcapitate. Hymenial trama hyphae cylindrical to subinflated, sometimes irregular, thin-walled, 3–8 μm wide. Pileipellis a cutis composed of cylindrical, rarely subinflated, thin-walled, 4–10 μm wide hyphae; terminal cells 37–87 × 5–8 μm, adpressed, cylindrical, clavate or subfusoid. Stiptipellis a cutis of cylindrical, parallel, thin-walled, clamped, 3–7 μm wide hyphae.

Habitat and distribution—Scattered or gregarious on soil under mixed forest dominated by Fagaceae trees. Known to be from eastern China and Korea.

Specimens examined—China. Jiangsu Province, Nanjing City, Purple Mountain, 19 June 2021, alt. 150 m, Zi-Hang Zhang (GDGM85846); same location, 28 June 2021, Zi-Hang Zhang (GDGM85852, GDGM85853); Anhui Province, Huangshan National Scenic Area, 26 August 2021, alt. 1400 m, Chen-Jie Jiang (GDGM85142). Zhejiang Province, Lishui City, Jingning Town, Wangdongyang Alpine Wetland Nature Reserve 22 September 2016, Rui-Lin Zhao (HMAS279296, HMAS279292); same location, 23 September 2016, Rui-Lin Zhao (HMAS279262, HMAS279284).

Figure 6. Basidiomata of Cantharellus albovenosus. (a,b) GDGM85852. (c,d) GDGM85846. (e) GDGM85142. Bars = 2 cm.
Figure 7. *Cantharellus albovenosus*. (a) Basidia, basidiola and elements of the subhymenium. (b) Basidiospores. (c) Pileipellis. Bars: (a,b) = 10 μm; (c) = 20 μm.

Notes—*Cantharellus albovenosus*, recently reported from South Korea, is characterized by the combined features of the orange to reddish orange pileus, white to orange white and relatively well-developed lamellate hymenophore, the orange to reddish orange stipe, and the ellipsoid to nearly globose basidiospores (7–8.5 × 5–6 μm) [11]. Phylogenetically, *C. albovenosus* and *C. phloginus* clustered together in an almost similar phylogenetic position, and cannot be separated in our multi-locus phylogenetic tree (Figure 1). Morphologically, *C. phloginus* can be distinguished by its pastel red to pastel pink pileus and stipe, pale yellow to yellowish orange hymenophore and large basidiospores [6.8–9.5 (–12) × 5–7 μm] [22].

Ecologically, *C. albovenosus* is known from subtropical regions of South Korea and eastern China; meanwhile, *C. phloginus* is currently only known from tropical regions of southwest China. The distinguishable morphological features and different growth habits supported them as two distinct species, but some more effective molecular markers are needed to distinguish the two species.

*Cantharellus citrinus* Buyck, R. Ryoo & Antonin, in Buyck, Hofstetter, Ryoo, Ka and Antonin, MycoKeys 76: 35 (2020); Figures 8 and 9.

Basidiomata small-sized. Pileus 15–45 mm broad, convex, with involute margin when young, then gradually to broadly infundibuliform with depressed center, irregularly undu-
late or slightly cracked margin when old; surface dry or hygrophanous, glabrous or finely subtomentose, greenish yellow, light yellow, yellow to yellowish orange (1A4–4A4, 1A7–4A7). Context yellowish white, 1 mm thick in the center of the pileus, sharply attenuate towards margin, unchanging when exposed. Hymenophore decurrent, subdistant, composed of bifurcate, less than 1 mm high veined folds, particularly towards pileus margin, white to yellowish white (1A2–3A2), unchanging when bruised. Stipe 15–30 × 3–5 mm, central, cylindrical or slightly tapering towards base, hollow, glabrous, concolorous with pileus or paler, unchanging when handled. Odor fruity and pleasant. Taste mild.

Basidiospores 7–9 × 5–6(6.5) µm, $L_m \times W_m = 7.77(\pm 0.47) \times 5.29(\pm 0.40)$ µm, $Q = (1.17)1.23–1.6(1.64)$, $Q_m = 1.47 \pm 0.11$; broadly elliptical to subglobose, smooth, guttulate, thin-walled. Basidia 55–65 × 7–8 µm, 4–6-spored, narrowly clavate, colorless to hyaline in KOH; sterigmata 5–10 µm long. Pileipellis a cutis with long, repent and occasionally interwoven hyphae, subcylindrical cells that are 5–15 µm wide, thin-walled. Stipitipellis a cutis of cylindrical, parallel hyphae, 5–10 µm wide. Clamp connections abundant in all tissues.

Habitat and distribution—Gregarious on soil under mixed forests in southwest China. Known from southwest China and Korea.

Figure 8. Basidiomata of *Cantharellus citrinus*. (a,b) GDGM86143. (c) GDGM86141. (d) GDGM80723. Bars = 2 cm.
Figure 9. Cantharellus citrinus. (a) Basidiospores. (b) Basidia, basidiola and elements of the subhymenium. (c) Pileipellis. Bars: (a, b) = 10 μm; (c) = 20 μm.

Specimen examined—China. Guizhou Province, Guiyang City, Longli County, Guanyin Village, bought from a wild mushroom market, 1 July 2020, alt. 1000 m, Ming Zhang (GDGM80825); Same location, 16 June 2020, Ting Li (GDGM80724, GDGM80723); 7 July 2021, Ming Zhang (GDGM86140, GDGM86141, GDGM86142, GDGM86143).

Notes—Cantharellus citrinus, recently reported from Korea [11], is characterized by its small basidiomata, greenish yellow to yellowish orange pileus, white to yellowish white hymenophore strongly bifurcate at pileus margin, glabrous and hollow stipe, and broadly elliptical to subglobose basidiospores [7–9 × 5–6 (6.5) μm]. In the multi-locus phylogenetic tree, samples of C. citrinus formed a well-supported monophyletic terminal clade, and can be easily distinguished from other Cantharellus species.
Morphologically, *C. citrinus* might be easily identified as a species in the subg. Parvacantharellus by the small basidioma with a greenish yellow to yellowish orange pileus, and similar to *C. galbanus* Ming Zhang, C.Q. Wang & T.H. Li and *C. luteovirens* Ming Zhang, C.Q. Wang & T.H. Li. However, *C. galbanus*, recently reported from tropical China, differs in its smaller basidiomata, relatively well-developed hymenophore, and smaller basidiospores (6–7.5 × 4.8–5.5 μm) [13]; *C. luteovirens*, recently reported from subtropical China, differs in its yellow to yellowish-orange pileus, yellowish white to pale yellow hymenophore and smaller basidiospores (6–7.5 × 4.5–6 μm) [13].

**Cantharellus phloginus** S.C. Shao & P.G. Liu, in Shao, Buyck, Tian, Liu and Geng, Mycoscience 57(2): 146 (2016); Figures 10 and 11.

Basidiomata small to medium-sized. Pileus 20–60 mm broad, applanate with a concave center, margin incurved at first, then becoming applanate or slightly reflexed with age, glabrous, pastel red to pastel pink (7A4–11A4); Context 2–3 mm thick, white, with pinkish hues under pileipellis, unchanging when bruised; Hymenophore decurrent, well-developed, lamellate ridges with anastomosing veins, forking towards pileus margin, pale yellow to light yellow (3A3–4A3), unchanging when touched. Stipe 20–40 × 4–8 mm, central, solid, subcylindrical, or slightly tapering towards base, glabrous, concolorous with pileus or paler to pinkish with yellowish hues, unchanging when handled. Odor fruity. Taste pleasant.

Basidiospores 6.8–9.5 (–12) × 5–7 μm, $L_m \times W_m = 8.49(\pm1.09) \times 5.71(\pm0.69)$ μm, $Q = (1.33)1.36–1.6(1.7), Q_m = 1.49 \pm 0.18$; broadly ellipsoid to subglobose, smooth, guttulate. Basidia 60–95 × 8–10 μm, 2–6-spored, narrowly clavate, colorless to hyaline in KOH; sterigmata 3–7 μm long. Hymenophoral trama composed of cylindrical interwoven hyphae 3–13 μm in diam. Pileipellis a subcutis, composed of long, repent, branched, and slightly interwoven hyphae, with subcylindrical cells in 3–13 μm wide, thin-walled. Clamp connections abundant in all tissues.

**Figure 10.** Basidiomata of *Cantharellus phloginus* (GDGM79007). Bar = 5 cm.
Habitat and distribution—Gregarious or caespitose under mixed forests, dominated by Pinus sp. and Castanopsis in the tropical forest. Currently known to be southwest China.

Specimens examined—China. Yunnan Province, Puer City, alt. 1500 m, 26 August 2009, S.C. Shao 98 (HKAS58208, holotype); Puer City, bought from a mushroom market, alt. 1500 m, 28 September 2019, Ming Zhang (GDGM79007).

Notes—Cantharellus phloginus, recently reported from southwest China, is characterized by its pastel red to pastel pink pileus and stipe, pale yellow to yellowish orange, well-developed hymenophore, and ellipsoid basidiospores [6.8–9.5 (–12) × 5–7 µm] [22]. Morphologically, C. phloginus is similar to C. cinnabarinus and C. texensis Buyck & V. Hofst with the pinkish red pileus color. However, C. cinnabarinus differs in its small basidiomata, reddish pink pileus, small basidiospores [(6.4) 6.7–7.5 (8.1) × (3.7) 3.8–4.6 (5.2) µm] and thick-walled pileipellis [32]; C. texensis differs in its slender basidiomata, reddish pink pileus, relatively well-developed hymenophore, small basidiospores [8–8.95 (9.4) × (3.3) 3.7–4.3 µm], and thinner-walled pileipellis that is faintly covered with zebroid incrusta-
tion [32]. Ecologically, C. phlogin us occurs under trees of Pinus sp. and Castanopsis sp. in tropical regions of southwest China, while C. cinnabarinus and C. texensis occur on sandy loam in oak-pine forests in temperate regions of North America [32].

3.2.2. Cantharellus subgen. Parvocantharellus Eyssart. & Buyck

**Cantharellus convexus** Ming Zhang & T.H. Li sp. nov.; Figures 12 and 13.

MycoBank: MB843659.
GenBank: OM978941 for LSU, ON119053 for tef1 and ON119037 for rpb2.

Etymology—“convexus” refers to the convex of the pileus center.

Diagnosis—This species can be easily distinguished from others in Cantharellus by its small basidiomata, yellowish white pileus, distant and well-developed lamellate hymenophore with or without bifurcate low veins and smaller basidiospores at 6–7 × 4.5–5 μm.

Type—China. Guangdong Province, Shaoguan City, Nanling National Nature Reserve, alt. 800 m, 29 July 2017, Ming Zhang (GDGM70307).

Basidiomata small-sized. Pileus 5–12 mm broad, convex when young, then gradually to nearly appplanate with a central shallow depression at maturity; surface dry, tomentosus, mostly yellowish white, pale yellow to pale orange (2A2, 2A3–5A3), but in some specimens can be yellowish brown to brown, with a deeper center to olive brown to yellowish brown (4E5–5E5); margin wavy, incurved when young, decurved to slightly upturned at maturity, unchanging when handled. Context yellowish white, thin, unchanging when exposed. Hymenophore decurrent, lamellate ridges distant, relatively well developed, occasionally forking towards pileus margin, with or without bifurcate low veins between ridges, yellowish white to pale yellow (2A2–4A2, 2A3–4A3), unchanging when bruised. Stipe 10–20 × 1.5–3 mm, central, cylindrical or slightly tapering towards base, glabrous or faintly scaly, concolorous with pileus or paler, unchanging when handled. Odor not distinct.

Basidiospores (50/1/2) 6.0–7.0 × 4.5–5.0 μm, Lm × Wm = 5.71 ± 0.64 × 4.87 ± 0.49 μm, Q = (11.1–1.27(1.37), Qm = 1.17 ± 0.07, broadly ellipsoid to subglobose, smooth, guttulate. Basidia 32–50 × 7–9 μm, 4–6-spored, narrowly clavate, colorless to hyaline in KOH, sterigmata 3–7 μm long. Hymenophoral trama irregular, composed of colorless and branched hyphae, 5–22 μm wide, septate, thin-walled. Pileipellis a cutis with long, repent, branched, and usually interwoven hyphae consisting of subcylindrical cells in 3–15 μm wide, thin-walled; terminal cells appressed to suberect, mostly cylindrical, up to 110 μm long, 5–15 μm wide. Stipitipellis a cutis of cylindrical, parallel hyphae, 3–10 μm wide; terminal cells clavate or cylindrical. Clamp connections abundant in all tissues.

![Figure 12](image_url). Basidiomata of Cantharellus convexus. (a) GDGM70307. (b) GDGM54841. Bars = 2 cm.
Figure 13. Cantharellus convexus. (a) Basidiospores. (b) Basidia, basidiola and elements of the subhymenium. (c) Pileipellis. Bars: (a,b) = 10 μm; (c) = 20 μm.

Habitat and distribution—Gregarious or scattered under broadleaf forests (dominated by Fagaceae trees) in subtropical China. Currently known from Guangdong and Hunan Province, Southern China.

Additional specimens examined—China. Hunan Province, Chenzhou City, Sanjiangkou Town, Jiulongjiang National Forest Park, under Castanopsis hystrix mixed with other broadleaf trees, alt. 200 m, 3 August 2017, Ming Zhang (GDGM54841).

Notes—Cantharellus convexus is characterized by its small basidiomata, convex pileus covered with fibrillose scales, distant and well-defined lamellate hymenophore without anastomosis between the folds, broad elliptic to subglobose basidiospores and thin-walled hyphae of the pileipellis. These traits taxonomically enable the placement of C. convexus into subg. Parvocantharellus.

Phylogenetically, two specimens of C. convexus formed an isolated lineage in subg. Parvocantharellus, and are closely related to C. tabernensis. A BLAST result of ITS sequence in the GenBank database also demonstrated that the similarity between C. convexus and C. tabernensis (JN944012, O7.064) is 93.7%. However, C. tabernensis, originally reported from North America, differs in its more robust basidiomata, dull orange-yellow to yellowish-
brown pileus, vivid orange-yellow hymenophore and stipe and larger basidiospores (6–9 × 4.4–5.9 µm) [40]. Additionally, C. tabernensis, currently only known from Texas, Louisiana and Mississippi in North America, occurs in well-drained (sandy) soil in mixed woods, and near to Pinus elliottii Engelm. Meanwhile, C. convexus was found in broadleaf forests in southern China, close to Fagaceae trees. Another North America species, C. appalachiensis, also demonstrates a close relationship with C. convexus. However, C. appalachiensis differs in its larger and more robust basidiomata, with a drab yellow to dull brown pileus applanate with the center depressed, surface locally dull-grayish due to aggregate minute fibrils and with larger basidiospores (6.6–8.9 × 4.4–5.9 µm) [41,42].

Morphologically, C. convexus is similar to C. austrosinensis Ming Zhang, C.Q. Wang & T.H. Li, C. koreanus Buyck, Antonín & Ryoo and C. luteovirens. However, C. austrosinensis differs in its pastel yellow to greyish-yellow pileus, usually with a greyish-orange to brownish-orange center, broader basidiospores (6–8 × 4.8–6 µm) and strictly associated with coniferous trees (Pinus massoniana) [13]; C. koreanus, originally described from the temperate region of the Republic of Korea, differs in its dirty yellow-brown to pale brown pileus usually with a brown to dark brown center and larger basidiospores [6–8 (–9) × 4.2–5.5 (–6.5) µm] [11]; C. luteovirens differs in its yellow to orange pileus, greyish-yellow to greyish-orange hymenophores, broadly ellipsoid to subglobose basidiospores (7–8 × 5.2–6.5 µm) and is currently only found be associated with Acacia trees [13].

_Cantharellus neopersicinus_ Ming Zhang, T.H. Li & X.Y. Chen sp. nov. Figures 14 and 15.

Figure 14. Basidiomata of _Cantharellus neopersicinus_. (a–e) GDGM87366. (f,g) GDGM85145. Bars: (a,b,d–f) = 2 cm; (c,g) = 5 cm.
Figure 15. Cantharellus neopersicinus. (a) Basidiospores. (b) Basidia, basidiola and elements of the subhymenium. (c) Pileipellis. Bars: (a,b) = 10 µm; (c) = 20 µm.

MycoBank: MB843660
GenBank: OM978943 for LSU, ON119057 for tef1 and ON119042 for rpb2

Etymology—refers to the color similar to Cantharellus persicinus.

Diagnosis—The pastel red to pink pileus, white to pinkish hymenophore with strongly bifurcate low veins and ellipsoid to subglobose [(6–)7–8.5(–9) × (4–)4.5–5.5(–6) µm], make C. neopersicinus easily distinguished from other species in the subg. Parvocantharellus.

Type—China. Guangdong Province, Leizhou City, Fangcha Village, under Eucalyptus robusta, alt. 105 m, 16 October 2021, Xiu-Yuan Chen (GDGM87366).

Basidiomata small-sized. Pileus 15–45 mm broad, convex when young, then gradually to nearly applanate with a central shallow depression at maturity; surface dry, glabrous,
pastel red, pastel pink to pink (8A4–12A4); margin incurved when young, reflexed with age, wavy, sometimes irregularly split; unchanging when touched. Context thin, reddish white or pinkish (8A2–12A2), unchanging when exposed. Hymenophore decurrent, but clearly demarcated with stipe, lamellated ridges close to subdistant, poorly-developed, strongly forking towards pileus margin, with bifurcate low veins between ridges, white to pinkish, unchanging when bruised. Stipe 15–40 × 3–8 mm, central, cylindrical or slightly tapering towards base, hollow, glabrous, concolorous with pileus, unchanging when handled. Odor fruity. Taste mild.

Basidiospores (50/2/2) (6–)7–8.5(–9) × (4–)4.5–5.5(–6) µm, Lµm × Wµm = 7.78(±0.64) × 4.871(±0.46) µm, Q = (1.2)1.4–1.77(2), Qm = 1.6 ± 0.15, ellipsoid to subglobose, smooth, guttulate. Basidia 45–62 × 7–9 µm, 4–6-spored, narrowly clavate, colorless to hyaline in KOH, sterigmata 3–7 µm long. Hymenophoral trama irregular to subregular, composed of colorless and branched hyphae, 8–16 µm wide, septate, thin-walled. Pileipellis a cutis with long, repent to suberect, branched, and slightly interwoven hyphae, subcylindrical cells in 8–15 µm wide, thin-walled; terminal cells appressed, mostly cylindrical, up to 100 µm long, 5–15 µm wide. Stipitipellis a cutis of cylindrical, parallel hyphae, 3–8 µm wide, terminal cells cylindrical. Clamp connections abundant in all tissues.

Habitat and distribution—Gregarious or scattered under Eucalyptus robusta Smith in tropical China. Currently known from Guangdong Province, Southern China.

Additional specimens examined—China. Guangdong Province, Leizhou City, Fangcha Village, alt. 105 m, 25 October 2021, Xiu-Yuan Chen (GDGM85145).

Notes—Cantharellus neopersicinus is characterized by its small basidiomata, pastel red to pink pileus, poorly-developed lamellae hymenophore with strongly bifurcate low veins and ellipsoid to subglobose basidiospores [(6–)7–8.5(–9) × (4–)4.5–5.5 (–6) µm]. Phylogenetic analyses based on multi-locus datasets demonstrated that C. neopersicinus was well nested into the subg. Paroceantharellus, formed a well-supported terminal clade, and was closely related to C. albus S.P. Jian & B. Feng and C. luteolus. However, C. albus, recently reported from China, can be easily distinguished by its white basidiomata slightly changing to yellowish when bruised, a spicy taste and smaller basidiospores (5.5–7.5 × 4.5–6 µm) [12,13]; C. luteolus differs in its small basidiomata, yellow to orange pileus, greyish-yellow to greyish-orange hymenophore and oval to subglobose basidiospores (7–8 × 5.2–6.5 µm) [13].

Morphologically, the pastel red to pink pileus color is easily reminiscent of the species C. cinnabarinus, C. coccolobae Buyck, P.-A. Moreau & Courtec., C. phloginus and C. persicus. However, the former three species belong to the subg. Cinnabarinus, and can be easily distinguished from C. neopersicinus by the genetic distances. Besides, C. cinnabarinus differs in its cinnabar red to bright orange pileus, thick-walled hyphal terminal cells of pileipellis and smaller basidiospores (6.7–7.57 × 3.82–4.68 µm) [32]. Cantharellus coccolobae differs in its salmon orange hymenophore, white stipe context partly changing to yellowish when cut, large basidiospores [(7.9) 8.3–9.3 (9.8) × (4.8) 5.3–5.9 (6) µm], longer basidia up to 120 µm and the thick-walled hyphae of the pileipellis. Additionally, C. coccolobae was reported to be strictly associated with Coccoloba trees, while C. neopersicinus is under Eucalyptus trees [33]. Cantharellus phloginus is redescribed in this study and differs in its darker pileus color, pale yellow to light yellow hymenophore, white context and larger basidiospores [6.8–9.5 (~12) × 5–7 µm]. Cantharellus persicus, originally reported from North America, differs in its more robust basidiomata, larger basidiospores (9.6–10.9 × 6.3–7.1 µm), and thick-walled cells of pileipellis. In addition, C. persicus is reported to be associated with oaks or eastern hemlock [32,43,44].

Cantharellus koreanus Buyck, Antonin & Ryoo, in Antonin, Hofstetter, Ryoo, Ka and Buyck, Mycol. Progr. 16(8): 755 (2017); Figures 16 and 17.

Basidiomata small-sized. Pileus 15–40 mm broad, convex at first, then gradually applanate with slightly an umbilicate centre; margin involute at first, undulate; surface dry, glabrous or finely tomentose-fibrillose at centre, mostly pale yellow to light yellow (1A3–4A3,1A4–4A4), olive brown to light brown (4D4–5D4) at centre, with obscurely sulcate
at margin. Hymenophore with lamellate ridges; ridges broadly adnate to subdecurrent, with a clearly delimitation from the stipe surface, well-developed, bifurcate and with interconnected low veins, up to 1 mm high, yellowish white (2A2–4A2), unchanging when bruised. Stipe 10–40 mm long, 2–5 mm thick, subcylindrical to cylindrical, slightly enlarged downward, but sometimes tapering towards base, glabrous or with faintly scaly, hollow, concolorous with pileus, darker and more somber than lamellae ridges. Odor fruity. Taste mild.

Basidiospores 5–8 × (4–) 4.5–6 µm, \( L_m \times W_m = 7.05(\pm 0.51) \times 5.192(\pm 0.34) \) µm, \( Q = (1.08)1.2–1.45(1.6) \), \( Q_m = 1.36 \pm 0.097 \), ellipsoid, broadly ellipsoid, thin-walled. Basidia 40–70 × 8–12 µm, 4–6-spored, narrowly clavate, sometimes subcapitate, thin-walled, clamped. Hymenophoral trama composed of clavate, subcylindrical, subregular, branched, thin-walled, clamped hyphae 5–12 µm wide. Pileipellis a cutis, composed of cylindrical, thin-walled hyphae, 5–15 µm wide; terminal cells clavate, fusoid to cylindrical, up to 100 µm long. Stipitipellis a cutis of cylindrical, parallel, branched, thin-walled hyphae 2–9 µm wide. Clamp connections abundant in all tissues.

Habitat and distribution—Gregarious or scattered under broadleaf forests (dominated by Fagaceae trees) in subtropical regions of China. Known from Hunan Province, China and Korea.

Specimens examined—China, Hunan Province, Zhangjiajie City, Zhangjiajie National Forest Park, alt. 1200 m, 17 July 2020, Wei-Qiang Qin (GDGM79233); same location, alt. 1100 m, 5 July 2021, Wei-Qiang Qin (GDGM85306).

Notes—Cantharellus koreanus, recently reported from Korea, is firstly reported from China in this study. It is characterized by the small basidiomata, the dirty yellow-brown to pale brown pileus with a brown to dark brown center, the well-development hymenophoral ridges with yellow tinge, and the ellipsoid to broadly ellipsoid basidiospores 6–8 (–9) × 4.2–5.5 (–6.5) µm in Antonin et al. [11] and 5–8 × (4–) 4.5–6 µm in this study.

Figure 16. Basidiomata of Cantharellus koreanus. (a,b) GDGM79233. (c,d) GDGM85306. Bars = 2 cm.
Phylogenetically, *C. koreanus* is closely related to *C. appalachiensis*, *C. austrosinensis* and *C. tabernensis*. Indeed, *C. koreanus* is similar to *C. appalachiensis*, *C. austrosinensis* and *C. tabernensis* in morphology. However, *C. appalachiensis* differs in its larger and more robust basidiomata (pileus up to 50 mm broad), drab yellow to dull brown pileus, narrower basidia (5.5–9 μm in diam.), shorter and slightly thickened end cell of pileipellis, narrower hyphae of hymenophoral trama, and association with oaks and other hardwoods [41,45,46]; *C. austrosinensis* differs in its smaller basidiomata, pastel yellow to greyish-yellow pileus with a greyish-orange to brownish-orange center, shorter and narrower basidia (50–55 × 7–9 μm), interwoven hyphae of pileipellis, and symbiosis with coniferous trees [13]; *C. tabernensis* differs in its dull orange yellow to yellowish brown pileus, vivid orange yellow hymenophore and stipe, shorter and narrower basidia (35–55 × 5–8 μm), and distribution in North America [40,42,46].

In addition, several species were recently reported from China, and are also similar to *C. koreanus* in morphology, such as *C. galbanus*, *C. luteolus* Ming Zhang, C.Q. Wang & T.H. Li, *C. luteovirens* and *C. sinominor* Ming Zhang, C.Q. Wang & T.H. Li [13], but they can be easily separated from each other by the large genetic distances.
3.3. Key to Species of Subgenus Cinnabarinus in China

1 Basidiomata with pastel red or reddish orange tinge.................................................2
1' Basidiomata without red tinge....................................................................................4
2 Pileus: small, always <20 mm broad.................................................................C. sinocinnabarinus
2' Pileus: relatively large, usually >20 mm wide.........................................................3
3 Basidiospores: 7-8.5 × 5-6 µm.................................................................C. albovenosus
3' Basidiospores: 6.8-9.5 (12) × 5-7 µm................................................................C. phloginus
4 Pileus: greenish yellow to yellowish orange, hymenophore white to yellowish white; basidiospores: 7-9 × 5-6(6.5) µm.................................................................C. citrinus
4' Pileus: orange to orange-yellow, hymenophore pinkish white to orange white; basidiospores: 7.5-9 × 5-6.5 µm, basidia up to 100 µm..................................................C. chrysanthus

4. Discussion

In this study, the species diversity of C. subg. Cinnabarinus from China were examined. Five species were identified based on morphological characters and multi-locus phylogenetic analyses, containing two new species C. chrysanthus and C. sinocinnabarinus, two newly recorded species C. albovenosus and C. citrinus to China, and a known species, C. phloginus. In addition, three species belonging to the subg. Parvocantharellus were firstly discovered from China, including two new species C. convexus and C. neopersicus, and a new recorded species, C. koreanus.

In the past, the knowledge of species diversity of Cantharellus in China was poor and the specimens with large and yellow to orange basidiomata were mostly misidentified as the type species of the genus C. cibarius; meanwhile, specimens with small and yellow to orange red basidiomata were often inaccurately treated as C. minor Peck or C. cinnabarinus. However, a recent study proved that the distribution of C. cibarius is limited to northeast China, and the so-called “C. cibarius” reported from southwest China is actually C. yunnanensis W.F. Chiu [8]; meanwhile, the specimens labeled as “C. minor” in China were also proven to be misidentified, several new species with small basidiomata have been reported from China, and the distribution of C. minor with correctly identified specimens has not been found in China [13]. Cantharellus cinnabarinus was widely reported in China [19,21], but those photos of C. cinnabarinus used in the two literatures look like C. albovenosus; the correctly identified specimens of C. cinnabarinus in China have not been found in the present study. However, three morphologically similar species were discovered. The specimen HKAS58243 from southwest China, firstly identified as C. cinnabarinus in Shao et al. [20], was proven to be a native species of C. sinocinnabarinus in the present study. In addition, C. sinocinnabarinus seems to be restricted to subalpine habitats, and prefers symbiosis with Cyclobalanopsis delavayi and Pinus yunnanensis. The other two species, C. albovenosus and C. phloginus, are easily misidentified as C. cinnabarinus by their small basidiomata and reddish pileus color. However, C. albovenosus, recently reported from Korea, has been also found in eastern China, and C. phloginus seems to be restricted to tropical to subtropical regions in southwest China. Thus, we speculate that the specimens of “C. cinnabarinus” in Anhui, Guangdong, Jiangsu and Zhejiang provinces could be C. albovenosus, the distribution of “C. cinnabarinus” from tropical to subtropical regions of southwest China could be C. phloginus and the collections of “C. cinnabarinus” from subalpine regions of southwest China could be C. sinocinnabarinus.

Cantharellus neopersicus, newly discovered in this study, is a remarkable species in Cantharellus. Morphologically, C. neopersicus can be easily identified as a member of subg. Cinnabarinus or subg. Cantharellus, due to its pastel red to pink pileus and white to pinkish hymenophore; however, phylogenetic analyses demonstrated that it belongs to the subg. Parvocantharellus, which makes it the first species reported from China with pastel red to pink tinge in the subg. Parvocantharellus. Ecologically, C. neopersicus is distributed in tropical areas of southern China, and currently, the only known symbiosis is with Eucalyptus robusta.
**Cantharellus** subg. *Parvocantharellus*, mainly composed of small-sized species, was suggested to be a monophyletic group, and closely related to the subg. *Cinnabarinus* [3]. However, in the present study, the subgenus was proven to be paraphyletic or polyphyletic; two species of *C. cyanoxanthus* R. Heim ex Heinem. and *C. subcyanoxanthus* Buyck, Randrianj. & Eyssart formed an isolated clade in the multi-locus phylogenetic tree, and could represent a separate generic clade. The result is similar to previous studies [13,16].

Species in the two subgenera are difficult to separate in morphology because most species share similar characteristics of small basidiomata, abundant clamps and thin-walled hyphal ends at the pileus surface. However, they formed two separate clades in the multi-locus phylogenetic trees, and can be easily distinguished by molecular phylogenetic evidence. In addition, the species in subg. *Cinnabarinus* mostly own distinct orange, pink or red tinge, and can be distinguished from subg. *Parvocantharellus*. In future work, more detailed morphological observations are needed to provide new evidences for distinguishing the two subgenera.

**Author Contributions:** Conceptualization, M.Z. and T.-H.L.; methodology, M.Z. and C.-Q.W.; performing the experiment, M.Z.; phylogenetic analysis, M.Z. and Y.L.; validation, M.Z., C.-Q.W., Y.L., M.-S.G., S.-C.S., W.-Q.Q., W.-Q.D. and T.-H.L.; writing—original draft preparation, M.Z.; writing—review and editing, C.-Q.W., Y.L., S.-C.S. and T.-H.L.; visualization, M.Z.; supervision, T.-H.L.; project administration, M.Z.; funding acquisition, M.Z. All authors have read and agreed to the published version of the manuscript.

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