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Edible species of *Agaricus* (Agaricaceae) from Xinjiang Province (Western China)

ZHUO-REN WANG[1], LUIS A PARRA[2], PHILIPPE CALLAC[3], JUN-LIANG ZHOU[4,5], WEN-JIN FU[6], SAN-HAN DUI[6], KEVIN D HYDE[7,8,9] & RUI-LIN ZHAO[4*]

[1]*College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei Province 430070, China*
[2]*Avda. Padre Claret 7, 5° G, 09400 Aranda de Duero, Burgos, Spain*
[3]*INRA, UR1264, MycSA, CS 20032, BP81, F-33882 Villenave d'Ornon, France*
[4]*The State Key Lab of Mycology, Institute of Microbiology, Chinese Academic of Science, Beijing 100101, China*
[5]*Institute of Microbiology, Beijing Forestry University, Beijing 100083, China*
[6]*Institute of Agricultural Science, Agricultural Division 5 of Xinjiang Production and Construction Corps, Bortala, Xinjiang Province, China*
[7]*School of Science, Mae Fah Luang University, Chiang Rai 57100, Thailand*
[8]*Institute of Excellence in Fungal Research, and School of Science, Mae Fah Luang University, Chiang Rai 57100, Thailand*
[9]*Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 1145, Saudi Arabia*
** Corresponding author: zhaoruilin@gmail.com*

Abstract

Agaricus is a genus of macrofungi containing species with high edible and medicinal values. A survey of *Agaricus* species carried out around the Ebinur Lake, in Xinjiang Province of China, in 2012, yielded 19 collections that exhibited a red discolouration when bruised. Morphological and phylogenetic comparison with species of five sections of *Agaricus* possessing the red discolouration trait showed that the specimens belonged to four species. Two species, *A. sinodeliciosus* sp. nov. and *A. bitorquis* in section *Bivelares* and *A. desjardinii* sp. nov. and *A. padanus* in section *Nigrobrunnescentes*, both sections being monophyletic. The two new species proposed are described and illustrated and all species are compared with similar taxa or previous records. *Agaricus padanus* is reported outside Italy for the first time. All species are edible and consumed by locals, and appear to be adapted to relatively dry, cold and sandy habitats. Like *A. bitorquis*, *A. sinodeliciosus* produces large, delicious semihypogeous basidiomata in such conditions; it is therefore a good potential candidate for domestication and industrial production.

Keywords: taxonomy, phylogeny, ITS, cultivatable mushrooms

Introduction

The genus *Agaricus* L., the type genus of the Agaricaceae contains important edible and medicinal species (Largeteau *et al*. 2011; Wisitrassameewong *et al*. 2012; Camelini *et al.* 2013; Thawthong *et al*. 2014). Significant examples are *A. subrufescens* Peck and *A. bisporus* (J.E. Lange) Imbach; the latter commonly known as the button mushroom, is reported to account for 32% of the total world production of cultivated mushrooms in 1997 (Chang 1999).

The classification of *Agaricus* species was previously mainly based on temperate area species of the north hemisphere and comprised eight widely accepted sections (Parra 2008, 2013). Several potentially new sections were revealed by phylogenetic analysis of ITS sequence data (Zhao *et al*. 2011), but they comprised exclusively tropical and some subtropical species. There have been several recent studies on *Agaricus* with several new species reported from Australia, China and Thailand (Chen *et al.* 2012, 2015; Karunarathna *et al*. 2014; Lebel 2013; Gui *et al*. 2015; Lebel & Syme 2012; Li *et al*. 2014; Thongklang *et al.* 2014; Zhao *et al*. 2012, 2013).

A survey of *Agaricus* species was carried out around Lake Ebinur, in Bortala, Xinjiang Province of China, in 2012. This is the westernmost part of China near the border with Kazakhstan, where the main vegetation types are grasslands, desert steppes and moorlands with a continental dry climate (temperature on average from -12°C in January to 15°C in July). Morphological and phylogenetic analyses of the collections revealed four species; *Agaricus desjardinii* Z.R. Wang, K.D. Hyde & R.L. Zhao sp. nov. and *A. padanus* Lancon. in section *Nigrobrunnescentes* K. P. Peterson, Desjardin, & Hemmes; and *A. sinodeliciosus* Z.R. Wang & R.L. Zhao sp. nov. and *A. bitorquis* (Quél.) Sacc. in section *Bivelares* (Kauffman) L.A. Parra. The aim of this paper is to introduce the new taxa and describe the new collections.

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(Geml *et al*. 2008); however maybe these species do not support both cold and dryness or they do not fruit at the same time.

The species from sections *Bivelares* have high nutritional value. The consumed species in section *Sanguinolenti* (e.g. *A. sylvaticus*) and in section *Nigrobrunnescentes* (e.g. *A. lilaceps*) are considered as very tasty. However their cultivation on standard substrates has been limited or failed due to their slow mycelium growth rate (Hildén 2013). The four species reported here are consumed by locals in western China. The medium to large sized basidiomata and good taste of *A. sinodeliciosus* and *A. bitorquis* make them attractive and rewarding when collected, although this often requires digging since they are typically semihypogeous. *Agaricus bitorquis* is the only commercial cultivated species of the four taxa collected in this study. Attempts to cultivate these species is being carried out, and we have already obtained some encouraging results for *A. sinodeliciosus*.

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References

Callac, P., Billette, C., Imbernon, M. & Kerrigan, R.W. (1993) Morphological, genetic, and interfertility analyses reveal a novel, tetrasporic variety of *Agaricus bisporus* from the Sonoran Desert of California. *Mycologia* 85: 335–351. http://dx.doi.org/10.2307/3760617

Camelini, C.M., Rezzadori, K., Benedetti, S., Proner, M.C., Fogaça, L., Azambuja, A.A., Giachini, A.J., Rossi, M.J. & Petrus, J.C.C. (2013) Nanofiltration of polysaccharides from *Agaricus subrufescens*. *Applied Microbiology and Biotechnology* 97: 9993–10002. http://dx.doi.org/10.1007/s00253-013-5241-y

Cappelli, A. (1984) *Agaricus* L.: Fr. (*Psalliota* Fr.). Libreria editrice Biella Giovanna, Saronno, Italy, 558 pp.

Challen, M.P., Kerrigan, R.W. & Callac, P. (2003) A phylogenetic reconstruction and emendation of *Agaricus* section *Duploannulatae*. *Mycologia* 95: 61–73. http://dx.doi.org/10.2307/3761962

Chang, S.T. (1999) World production of edible and medicinal mushrooms in 1997 with emphasis on *Lentinus edodes* (Berk.) Sing. in China. *International Journal of Medicinal Mushrooms* 1: 291–301. http://dx.doi.org/10.1615/IntJMedMushr.v1.i4.10

Chen, J., Zhao, R.L., Karunarathna, S., Callac, P., Raspé, O., Bahkali, A.H. & Hyde, K.D. (2012) *Agaricus megalosporus*: a new species in section *Minores*. *Cryptogamie Mycologie* 33: 145–155. http://dx.doi.org/10.7872/crym.v33.iss2.2012.145

Chen, J., Zhao, R.L., Parra, L.A., Guelly, A.K., Kesel, A.D., Rapior, S., Hyde, K.D., Chukeatirote, E. & Callac, P. (2015) *Agaricus* section *Brunneopicti:* a phylogenetic reconstruction with descriptions of four new taxa. *Phytotaxa* 192: 145–168. http://dx.doi.org/10.11646/phytotaxa.192.3.2

Didukh, M. (2004) New data on rare and debatable species of the family Agaricaceae (Fr.) Cohn. *Ukrainian Botanical Journal* 61: 89–99.

Didukh, M., Vilgalys, R., Wasser, S.P., Isikhuemhen, O.S. & Nevo, E. (2005) Notes on *Agaricus* section *Duploannulati* using molecular and morphological data. *Mycological Research* 109: 729–740. http://dx.doi.org/10.1017/S0953756205002443

Edgar, R.C. (2004a) MUSCLE: multiple sequence alignment with high accuracy and high throughput. *Nucleic Acids Research* 32: 1792–1797.

http://dx.doi.org/10.1093/nar/gkh340

Edgar, R.C. (2004b) MUSCLE: a multiple sequence alignment method with reduced time and space complexity. *BMC bioinformatics* 5: 113.
http://dx.doi.org/10.1186/1471-2105-5-113

Gardes, M. & Bruns, T.D. (1993) ITS primers with enhanced specifity for Basidiomycetes: application to identification of mycorrhizae and rusts. *Molecular Ecology* 2: 113–118.
http://dx.doi.org/10.1111/j.1365-294X.1993.tb00005.x

Geml, J., Laursen, G.A. & Taylor, L.D. (2008) Molecular diversity assessment of arctic and boreal *Agaricus* taxa. *Mycologia* 100: 577–589.
http://dx.doi.org/10.3852/07-042R1

Gui, Y., Zhu, G.S., Callac, P., Hyde, K.D., Parra, L.A., Chen, J., Yang, T.J., Huang, W.B., Gong, G.L. & Liu, Z.Y. (2015) *Agaricus* section *Arvenses*: three new species in highland subtropical Southwest China. *Fungal Biology* 119 (2–3): 79–94.
http://dx.doi.org/10.1016/j.funbio.2014.10.005

Guinberteau, J., Callac, P. & Boisselet, P. (1998) Inventaire des communautés fongiques liées au Cupressus macrocarpa en zone littorale atlantique et données récentes sur les populations sauvages d'*Agaricus bisporus*. *Bulletin de la Société Mycologique de France* 114: 19–38.

Heinemann, P. (1978) Essai d'une clé de determination des genres *Agaricus* et *Micropsalliota*. *Sydowia* 30: 6–37.

Heinemann, P. (1980) Les genres *Agaricus* et *Micropsalliota* en Malaisie et en Indonésie. *Bulletin du Jardin Botanique National de Belgique* 50: 3–68.
http://dx.doi.org/10.2307/3667774

Heinemann, P. (1986) *Agarici* austroamericani VI. Apercu sur les *Agaricus* de Patagonie et de la terre de Feu. *Bulletin du Jardin Botanique National de Belgique* 56: 417–446.
http://dx.doi.org/10.2307/3668202

Heinemann, P. (1990) *Agarici* austroamericani VII: *Agariceae* des zones tempérées de 1'Argentine et du Chili. *Bulletin du Jardin Botanique National de Belgique* 60: 331–370.
http://dx.doi.org/10.2307/3668225

Hildén, K., Mäkelä, M.R., Lankinen, P. & Lundell, T. (2013) *Agaricus bisporus* and related *Agaricus* species on lignocellulose production of manganese peroxidase and multicopper oxidases. *Fungal Genetics and Biology* 55: 32–41.
http://dx.doi.org/10.1016/j.fgb.2013.02.002.

Huelsenbeck, J.P. & Ronquist, F. (2001) MrBayesian: Bayesian inferance of phylogeny. *Biometrics* 17: 754–755.

Huelsenbeck, J.P., Ronquist, F. & Bollback, J.P. (2001) Bayesian inference of phylogeny and in its impact on evolutionary biology. *Science* 294: 2310–2314.
http://dx.doi.org/10.1126/science.1065889

Karunarathna S.C., Guinberteau, J., Chen, J.,Vellinga, E.C., Zhao, R.L., Chukeatirote, E., Yan, J.Y., Hyde, K.D., & Callac, P. (2014) Two New Species in *Agaricus* Tropical Clade I. *Chiang Mai Journal of Science* 41: 771–780.

Kerrigan, R.W. (1986) *Agaricales of California. Vol. 6. Agaricaceae*. Mad River Press, Eureka, California, America. 1–62 pp.

Kerrigan, R.W., Callac, P. & Parra, L.A. (2008) New and rare taxa in *Agaricus* section *Bivelares* (*Duploannulati*). *Mycologia* 100: 876–892.
http://dx.doi.org/10.3852/08-019

Lanconelli, L. (2002) *Agaricus padanus* sp. nov. *Rivista di Micologia* 45: 29–37.

Largent, D.L. (1986a) *How to identify mushrooms to genus vol. 1. Macroscopic Features*. Mad River Press, Eureka, California, 166 pp.

Largent, D.L. (1986b) *How to identify mushrooms to genus vol. 3. Microscopic Features*. Mad River Press, Eureka, California, 148 pp.

Largeteau, M.L., Llarena-Hernández, R.C., Regnault-Roger, C. & Savoie, J.-M. (2011) The medicinal *Agaricus* mushroom cultivated in Brazil: biology, cultivation and non-medicinal valorization. *Applied Microbiology and Biotechnology* 92: 897–907.
http://dx.doi.org/10.1007/s00253-011-3630-7

Lebel, T. (2013) Two new species of sequestrate *Agaricus* (section *Minores*) from Australia. *Mycological Progress* 12: 699–707.
http://dx.doi.org/10.1007/s11557-012-0879-x

Lebel, T. & Syme, A. (2012) Sequestrate species of *Agaricus* and *Macrolepiota* from Australia: new species and combinations and their position in a calibrated phylogeny. *Mycologia* 104: 496–520.
http://dx.doi.org/10.3852/11-092

Li, S.F., Xi, Y.L., Qi, C.X., Liang, Q.Q., Wei, S.L., Li, G.J., Zhao, D., Li, S.J. & Wen H.A. (2014) *Agaricus taeniatus* sp. nov., a new member of *Agaricus* sect. *Bivelares* from northwest China. *Mycotaxon* 129: 187–196.
http://dx.doi.org/10.5248/129.187

Michalak, S. (2012) raxmlGUI: a graphical front-end for RAxML. *Organisms Diversity and Evolution* 12: 335–337.

http://dx.doi.org/10.1007/s13127-011-0056-0

Nauta, M.M. (2001) *Agaricus* L. and *Allopsalliota* Nanta et Bas. *In:* Noordeloos, M.E., Kyuper, T.W. & Vellinga E.C. (Eds.) *Flora Agaricina Neerlandica, Critical monographs on families of Agarics and Boleti occurring in the Netherlands. Vol. 5 Family Agaricaceae*. A.A. Balkema Publishers, Lisse, pp. 23–62.

Parra, L.A. (2008) *Agaricus L. Allopsalliota, Nauta & Bas, Fungi Europaei, Volume 1*. Edizioni Candusso, Alassio, 824 pp.

Parra, L.A. (2013) *Agaricus L. Allopsalliota, Nauta & Bas, Fungi Europaei, Volume 1A*. Candusso Edizioni s.a.s. Alassio, 1168 pp.

Parra, L.A., Muñoz, G. & Callac, P. (2014) *Agaricus caballeroi* sp. nov., una nueva especie de la sección Nigrobrunnescentes recolectada en España. *Micologia e Vegetazione Mediterranea* 29: 21–38.

Peterson, K.R., Desjardin, D.E. & Hemmes, D.E. (2000) Agaricales of the Hawaiian Islands. 6. Agaricaceae L. Agariceae: *Agaricus* and *Melanophyllum*. *Sydowia* 52: 204–257.

Ronquist, F. & Heulsenbeck, J.P. (2003) MrBayes 3: Bayesian phylogenetic inference under mixed models. *Bioinformatics* 19: 1572–1574.
http://dx.doi.org/10.1093/bioinformatics/btg180

Samgina, D.I. & Nam, G.A. (1989) Novyĭ vid iz roda *Agaricus* L.: Fr. *Izvestiya Akademii Nauk Kazakhskoĭ SSR Seriya Biologicheskaya* 156: 78–80.

Thawthong, A., Karunarathna, S.C., Thongklang, N., Chukeatirote, E., Kakumyan, P., Chamyuang, S., Rizal, M. Mortimer, P.E., Xu, J.C., Callac, P. & Hyde, K.D. (2014) Discovering and Domesticating Wild Tropical Cultivatable Mushrooms. *Chiang Mai Journal of Science* 41: 731–764.

Thongklang, N., Nawaz, R., Khalid, A.N., Chen, J., Hyde, K.D., Zhao, R.L., Parra, L.A., Hanif, M. , Moinard, M. & Callac, P. (2014) Morphological and molecular characterization of three *Agaricus* species from tropical Asia (Pakistan, Thailand) reveals a new group in section *Xanthodermatei*. *Mycologia* 106: 1220–1232.
http://dx.doi.org/10.3852/14-076

White, T.J., Bruns, T.L., Lee, S. & Taylor, J.W. (1990) Application and direct sequencing of fungal ribosomal RNA genes for phylogenetics. *In:* Innis, M.A., Gefand, D.H., Sninsky, J.J. & White, J.T. (Eds.) *PCR Protocols: A Guide to Methods and Applications*. Academic Press, San Diego, 482 pp.
http://dx.doi.org/10.1016/B978-0-12-372180-8.50042-1

Wisitrassameewong, K., Karunarathna, S., Thongklang, N., Zhao, R.L., Callac, P., Moukha, S., Ferandon, C., Chukeatirote, E. & Hyde, K.D. (2012) *Agaricus subrufescens*: A review. *Saudi Journal of Biological Sciences* 19: 131–146.
http://dx.doi.org/10.1016/j.sjbs.2012.01.003

Zhao, R.L., Desjardin, D.E., Callac, P., Parra, L.A., Guinbereau, J., Soytong, K., Karunarathna, S., Zhang, Y. & Hyde, K.D. (2013) Two species of *Agaricus* sect. *Xanthodermatei* from Thailand. *Mycotaxon* 122: 187–195**.**
http://dx.doi.org/10.5248/122.187

Zhao, R.L., Hyde, K.D., Desjardin, D.E., Raspé, O., Soytong, K., Guinberteau, J., Karunarathna, S.C. & Callac, P. (2012) *Agaricus flocculosipes* sp. nov., a new potentially cultivatable species from the palaeotropics. *Mycoscience* 53: 300–311.
http://dx.doi.org/10.1007/S10267-011-0169-5

Zhao, R.L., Karunarathna, S., Raspé, O., Parra, L.A., Guinberteau, J., Moinard, M., Kesel, A.D., Barroso, G., Courtecuisse, R., Hyde, K.D., Guelly, A.K., Desjardin, D.E. & Callac, P. (2011) Major clades in tropical *Agaricus*. *Fungal Diversity* 51: 279–296.
http://dx.doi.org/10.1007/s13225-011-0136-7