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Regional
Natural History**Formerly **Bollettino della Società dei Naturalisti in Napoli****Nomenclatural remarks on *Galdieria* (Galdieriaceae, Cyanidiophytina, Rhodophyta) with description of three new species and a new lectotypification**Emanuele Del Guacchio^{1,2}, Antonino Pollio^{1,2}, Antonino De Natale^{1,2*}DOI <https://doi.org/10.6093/2724-4393/10463>***Correspondence:**denatale@unina.it<https://orcid.org/>

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GuidaThis work is licensed under a Creative
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License**Abstract**

Cyanidiophytina are a subdivision of Rhodophyta represented by unicellular organisms often occurring in extreme or acidophilous environments and object of several ecological, physiological, phylogenetic, ontogenetic, and molecular studies. Recently, the genus *Galdieria*, a Cyanidiophytina member that includes four species (out of eleven in the whole subdivision), has been accommodated into a monogeneric order after an extensive taxonomic revision. However, the taxonomy of this group has not been completely assessed. In this contribution, some nomenclatural issues about Galdieriaceae are discussed, three new species are published validating previous names, and revised types supporting the current usage of *Galdieria sulphuraria* are presented.

Keywords: Agostino Galdieri, Cyanodiophytina, *Galdieria daedala*, *Galdieria maxima*, *Galdieria partita*, *Galdieria sulphuraria*, typification, nomenclature**Riassunto**

Le Cyanidiophytina sono una sub-divisione delle Rhodophyta, costituita da organismi unicellulari spesso presenti in ambienti estremi o acidofili e oggetto di numerosi studi ecologici, fisiologici, filogenetici, ontogenetici, e molecolari. Recentemente, il genere *Galdieria*, membro delle Cyanidiophytina che

comprende quattro specie (su undici dell'intera sub-divisione), è stato inserito in un ordine monogenerico dopo un'ampia revisione tassonomica. Tuttavia, la tassonomia di questo gruppo non è stata completamente valutata. In questo contributo vengono discusse alcune questioni nomenclaturali sulle Galdieriaceae e vengono pubblicate tre nuove specie che convalidano i nomi precedenti.

Parole chiave: Agostino Galdieri, Cyanodiophytina, *Galdieria daedala*, *Galdieria maxima*, *Galdieria partita*, *Galdieria sulphuraria*, tipizzazione, nomenclatura

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Introduction

Agostino Galdieri, born in Fisciano (a small town near Salerno, Campania region, southern Italy), on 15 June 1870, was assistant of the geological cabinet of the University of Naples since 1903 to 1911 (Baraldi & Marocchi, 2021). Later, he was Director of the Institute of Mineralogy of the Agricultural School of Portici, where he was also professor in Geology and Mineralogy (Adamo et al. 2007), but almost none is known of him after that date.

Albeit better known as a geologist, he first described a new eucaryotic alga in the extreme environment of fumaroles of Pozzuoli (Naples, Campania), despite the fact he could not observe its nucleus (Galdieri, 1899). He probably was not the very discoverer of that microorganism, because he cited a "*Protococcus vulcanicus*" gathered in the same place by the better-known Francesco Cesati in 1869, which could be the same alga (Balsamo, 1892). The new taxon was included by Galdieri (1899), with some doubt, in the genus *Pleurococcus* Meneghini (Chaetophoraceae Greville, Chaetophorales Wille, Chlorophyceae Wille), with the name *P.*

sulphurarius Galdieri. The taxon was repeatedly gathered in the XIX century (Albertano et al., 2000); however, Merola et al., (1982) first observed that this alga had been misplaced by Galdieri, especially based on its photosynthetic pigments (chlorophyll *a* and C-phycocyanin), which, together with the membrane organization of the chloroplast allow them to recognize a red alga (Sentzova, 1991). On account of its globular shape, reproduction by autospores, presence of vacuoles and numerous mitochondria, the taxon was transferred to the new genus *Galdieria* Merola, named in honour of Galdieri and included in the new monotypic family Galdieriaceae Merola (Cyanidiophyceae), then monotypic (Merola et al. 1982). *Galdieria sulphuraria* (Galdieri) Merola is therefore the type of the genus *Galdieria*, which remains the only one of the family but currently includes seven taxa, three of which not validly described (Park et al. 2023).

In fact, some years later, three further *Galdieria* species were described from Russia domains (Sentzova, 1991): "*G. daedala*", "*G. maxima*" (both from Kunashir Island), and "*G. partita*" (from Uzon caldera in

Kamchatka). The three names are regarded as invalid by Park et al. (2023) because of the requirements of the Art. 40.1 of the *International Code of Nomenclature for algae, fungi, and plants (Shenzhen Code)* (i.e., Turland et al. 2018). In any case, in her treatment, Sentzova (1991) amended the circumscription of genus *Galdieria* by adding new diagnostic features, such as the facultative heterotrophy. She distinguished the new taxa especially basing on cell size and on shape and number of chloroplasts.

A fourth species, i.e., *Galdieria phlegrea*, was first described by Pinto et al. (2007) who provided a short Latin diagnosis; it differs by the order of nucleotides in *rbcL* (plastid DNA), lacking any reliable difference in morphology and reproduction mechanism from *G. sulphuraria*. It was discovered near Naples in Pozzuoli as well, but in a different place than the *locus classicus* of *G. sulphuraria*, despite in both localities the two taxa are sympatric. Rather unusually, Park et al. (2023), after having enlightened the invalidity of the name by Pinto et al. (2007), did not validate it but re-used it, disregarding the previous authorship, and indicating a different type, actually publishing a new species. Moreover, the type was not gathered in the same locality sampled by Pinto et al. (2007) but in Turkey.

Apart this nomenclatural act, Park et al. (2023), basing on plastid sequences, proposed a revised classification of Cyanidiophytina, accomodating *Galdieria* in a new monotypic order (Galdieriales H.S.Yoon, S.I.Park, C.H.Cho & R.A.Andersen) and describing two new species, i.e., *Galdieria javensis* H.S.Yoon, S.I.Park & R.A.Andersen, first discovered by De Luca et al. (1981) on Mount Lawu in Java (Indonesia), and *G. yellowstonensis* H.S.Yoon, S.I.Park & T.

McDermott, from Yellowstone National Park, Wyoming (USA). However, even after their revision, several points remain insufficiently known and, according to Guiry & Guiry (2023), the taxonomic or nomenclatural status of several entities is “in some way unresolved and requires further investigation”.

In this contribution, we re-examine the genus *Galdieria* by a nomenclatural point of view, providing the validation of incorrect combinations and propose lectotypification.

Materials and Methods

The relevant literature was examined, paying special attention to the protologues (e.g., Galdieri, 1899; Schwabe, 1936; Merola et al. 1982; Sentzova, 1991; Park et al. 2023). Botanist abbreviations follow IPNI (2023) and Guiry & Guiry (2023), unless differently specified. Original material for untypified names and culture types were respectively searched at NAP (Herbarium of the University of Naples) and at ACUF (The Algal Collection at the University of Naples). The articles cited throughout the text follow Turland et al. (2018) (*Shenzhen Code*, hereafter *ICN*).

Results and discussion

The examined names are treated in alphabetical order.

Galdieria daedala - Sentzova (1991) published the name “*Galdieria daedala*” with a description, indication of habitat, locality (Kunashir Island, Kuril archipelago), type, and diagnosis, all in Latin. In this way, she apparently fulfilled the requirements of Arts. 40.1 (indication of type), 44.1 (employ of

Latin language) and 44.2 (accompanying illustration) for names of non-fossil algae published after 1 January 1958; of Art. 40.6 (explicit inclusion of the word "typus" or equivalent) for names published after 1 January 1991; and of Art. 40.7 (indication of collection or institution in which the type specimen is conserved) for names published after 1 January 1990. Therefore, despite the statement by Park et al. (2023), "*G. daedala*" is not at all a "nomen nudum" (= "without any diagnosis or description", see Glossary of ICN). However, a serious issue effectively occurs for the valid publication of the name: the type, as defined by Art. 8.4 of ICN, "may not be living organisms or cultures"; cultures of algae can be accepted as types "if preserved in a metabolically inactive state (e.g., by lyophilization or deep-freezing to remain alive in that inactive state)". To this regard, we note that on, or after 1 January 2019, "the protologue must include a statement that the culture is preserved in a metabolically inactive state". Sentzova (1991) indicated as the type a collection by L. M. Gerasimenko, which might be considered a specimen as defined by the Art. 8. However, even omitting that this collection might not be a single gathering as required by the footnote of Art. 8.2 (because the gathering time was extended from August to November 1988), if the type statement is compared with the information at page 70 of the same work (Sentzova, 1991), it is clear that such a "type" was a living culture, surely not in an inactivate status. We

might consider also the Art. 40.5 of ICN, which allows as the type of a microscopic alga an effectively published illustration even after 1990 (in this case, the figure A1 at p. 74 of Sentzova, 1991), but this is granted only "if there are technical difficulties of specimen preservation or if it is impossible to preserve a specimen that would show the features attributed to the taxon by the author of the name". These conditions, however, seem come against the fact that the diagnosis of "*G. partita*" is largely based on morphological traits (Sentzova, 1991) and no difficulty has been stated for fixation of *Galderia*. More important, the figure of "*G. partita*" in the original publication (Sentzova, 1991) is not explicitly associated with the word "type" and cannot be regarded as such (the association between the figure and the word "type" is mandatory after 1 January 1990: Arts. 40.3 and 40.6 of ICN). We have therefore to conclude that the name "*Galdieria daedala*" has not been validly published. The University Federico II of Naples preserves a strain of "*G. daedala*" corresponding to the material described by Sentzova (1991) and sent years ago by her to the Department of Biology (at that time Department of Plant Biology). In this way, it is possible to validate the name by her fulfilling all the requirements reported above.

Galdieria maxima – For this name, we can repropose the same observations already made for "*Galdieria daedala*". The corresponding taxon was first gathered in the acid thermal sources of Kunashir Island and published by

Sentzova (1991) according to the same scheme followed for "*G. daedala*".

Galdieria partita - Sentzova (1991) published the name "*Galdieria partita*" with a description, indication of habitat, locality (Kamtchatka in Asian Russia, Yellowstone Park in the US), an intended "type" and diagnosis, all in Latin. Also in this case, the protologue failed in type indication (see discussion about "*G. daedala*") and the name must be validated, eventually indicating as the holotype a specimen originated from the Russian strain obtained by Sentzova.

Galdieria phlegrea - The Art. 40.1 of ICN imposes that, on or after 1 January 1958, any name of a new taxon is not validly published unless the indication of its type. In addition, the Art. 40.6 of ICN provides that "on or after 1 January 1990, indication of the type must include one of the words "typus" or "holotypus", or its abbreviation, or its equivalent in a modern language". Pinto et al. (2007) evidently did not indicate a type specimen as defined by Art. 8.1 of ICN and the question is if in their protologue it is indicated as type a strain preserved in a metabolically inactive state according to Art. 8.4. It is to be noted that still in 2007, under particular conditions, an illustration could had been employed as type; however, any illustration or a reference to a published illustration is missing in Pinto et al. (2007) as well. These authors indicated instead an "authentic strain", i.e., the "strain number 291". Although that strain is not cited as the holotype, it is clear from the context that such "authentic strain" is the real

"type" strain. Effectively the word "type" is printed soon after the description of that strain and clearly refers to it, as it reports the *locus classicus* of the species, from where evidently the "authentic strain" was derived. Unfortunately, also in this case, the examination of the text clarifies that the "authentic strain" is a culture and not a specimen, so coming in contrast with Arts. 8, 40.1, 40.6 and 44.2 of ICN.

Galdieria sulphuraria - Galdieri (1899) published the name *Pleurococcus sulphurarius* without a classical scheme. He reported first the locality ("Solfatara di Pozzuoli") and observations about macroscopic appearance of the substrate coating caused by the alga (which are effectively notes on the alga itself), of its habitat, ontogeny, physiology, and taxonomic notes. The protologue is entirely in Italian, a language allowed at that time (Art. 44.1, Note 1 of ICN). The name appears only one time in the middle of the relation, which can be considered as the protologue (Art. 6.13, footnote). Galdieri provided also illustrations of the new taxon (Figs. "a-i"), which can be regarded as a single plate and obvious original material for lectotypification purposes (Art. 9.4 (b)). The combination *Galdieria sulphuraria* apparently was not validly published by Merola et al. (1982), because they should provide a full and direct reference to the basionym according to Art. 41.5 (this is mandatory since 1 January 1953). In particular, they seem to have failed in page indication (Art. 41.6). However, a reference to the pages is provided at the end of their

contribution (Merola et al. 1982, p. 194); this form is explicitly recommended against by the *ICN* (see Rec. 41A.1), but it does not make the combination invalid by itself. A more serious problem is that the reference encompasses all the pages of the contribution by Galdieri (1899). Nevertheless, as said above, the whole contribution by Galdieri can be quietly regarded as coextensive with the protologue (Art. 40.1, Note 1), because only dedicated to the description of morphology of *Pleurococcus sulphurarius*, illustrations, references, geographical data, discussion, and comments. Accepting as valid the new combination in Merola et al. (1982), the typification proposed by those authors appears as problematic. In fact, in the same paper, they indicated an "iconotypus" (i.e., the illustration in Galdieri 1899) and designated a "neotype" (cultures or specimens by Galdieri being lost since long time). It is clear from the context that "iconotypus" is to be intended merely as indication of "illustration accompanying the protologue" or "illustration of the type material studied by Galdieri". Differently, Merola et al. (1982) would have proposed two different elements as designed types, one by Merola and co-authors (the illustration) and the other one by Merola only (the neotype): this would make ineffective both designations, because Art. 7.11 of *ICN* provides that "designation of a type is achieved only if the type is definitely accepted as such by the typifying author". On the other hand, if the "iconotypus"

indication is not intended as a typification attempt, the proposed neotype cannot be accepted. In fact, a neotype can be selected only if original material is not available (Art. 9.13 of *ICN*). This is obviously not the case, because at least the illustration in Galdieri (1899) is original material itself (Art. 9.4 of *ICN*). For this reason, a lectotypification of the Galdieri's name is still due. In addition, designation of an epitype would be appropriate according to Art. 9.9 of *ICN*, because *Galdieria phlegrea* cannot be distinguished from *G. sulphuraria* only by means of morphological traits (Pinto et al. 2007, Park et al. 2023). Finally, Galdieri (1899, p. 162, footnote 2) cited a "material" of "*Protococcus vulcanicus*" preserved by F. Balsamo. However, this material cannot be regarded as a syntype (Art. 9.6 of *ICN*), which would claim priority in lectotypification (Art. 9.12 of *ICN*). In fact, Galdieri, writing that that material could not be compared with those collected by him, did not associate it to the name: "è impossibile tenerne calcolo" (= "it is impossible to take it into account"). In any case, this material is now lost as well.

Nomenclatural synopsis of *Galdieria*

Galdieria Merola in Giorn. Bot. Ital. 115(4-5): 193. 1982 ["1981"]. Generitype: *Pleurococcus sulphurarius* Galdieri [= *Galdieria sulphuraria*] (designated by Merola in Merola et al. 1982: 193).

***Galdieria daedala* Sentzova ex Pollio, De Natale & Del Guacchio, spec. nov.**

Diagnosis: Ab omnibus speciebus congeneribus chloroplastis daedalis variiformibus, necnon forma autosporarum matricium differt. In omnibus vitae gradibus intimum stratum parietis cellulae exsertum versus membranam plasmatis.

Description: Cells globose or almost so, 2.5–8.0 µm in diam., growing under mixo- and heterotrophy up to 10.0 µm. Chloroplast one, parietal, with envelope labyrinth-shaped in autospores and young cells, plurilobate in mature cells. Autospores 4–8–16. In all stages of the cell life the innermost layer of the cell wall protruded towards the plasma membrane. Membrane of parent cells enlarged to the shape of autospores, empty and lentiform (both diagnosis and description are modified from Sentzova 1991: 75).

Holotypus: NAP, barcode NAP0002462, prepared in 4% formalin from the living strain ACUF 133, isolated from URSS, Kamtchatka, Uzon and sent by O. Ju. Sentzova.

Illustration: Figure 1 (A-C) from the holotype (present study); additional illustrations in Sentzova (1991: 74, figs. «B» 1-11) and in Pinto et al. (2003: 22, figs. 26-27).

Galdieria javensis H.S.Yoon, S.I.Park & R.A.Andersen, in J. Phycol. 59: 452. 2023. Type (holotype): No. 02667126 (NY), from culture strain NIES-3638; isotypes at NY (No. 02667127), SKK (No. SKK003971), MABIK (No. MABIK_AL00089917) (Park et al. 2023: 452). Illustration: Fig. 2j in Park et al. (2023: 451).

Galdieria maxima Sentzova ex Pollio, De Natale & Del Guacchio, spec. nov.

Diagnosis: A speciebus ceteris Galdieriae magnitudine, chloroplasto semper reticulato differt.

Description: Cells globose. After any nutrition 6.0–16.5 µm in diameter. Chloroplast single, net-shaped. Autospores 2–4–8, irregularly globose or conical. Membrane of parent cells empty and bag-shaped (both diagnosis and description are modified from Sentzova 1991: 75).

Holotypus: NAP, barcode NAP0002463, prepared in 4% formalin from the living strain ACUF 132 from URSS, Kamtchatka, Uzon and sent by O. Ju. Sentzova.

Illustration: Figure 1 (D-F) from the holotype (present study); additional illustrations in Sentzova (1991: 74, figs. «E», 1-9) and in: Pinto et al. (2003: 23, Figs. 30-31).

Galdieria partita Sentzova ex Pollio, De Natale & Del Guacchio, spec. nov.

Diagnosis: Species Galdieriae daedalaе dimensionibus cellularum similis est sed ab ea et speciebus congeneribus forma chloroplastorum recedit.

Description: Cells globose, 2.5–8.0 µm in diameter, growing by mixo- and heterotrophy up to 11.0 µm. Chloroplast parietal, always single and cup-shaped in autospores, always single and belt- or dumbbell-shaped in young cells, one and subdivided in many elongate, sac-like elements in mature cells, which they almost completely cover. Autospores 4–8, conical. Membrane of parent cells

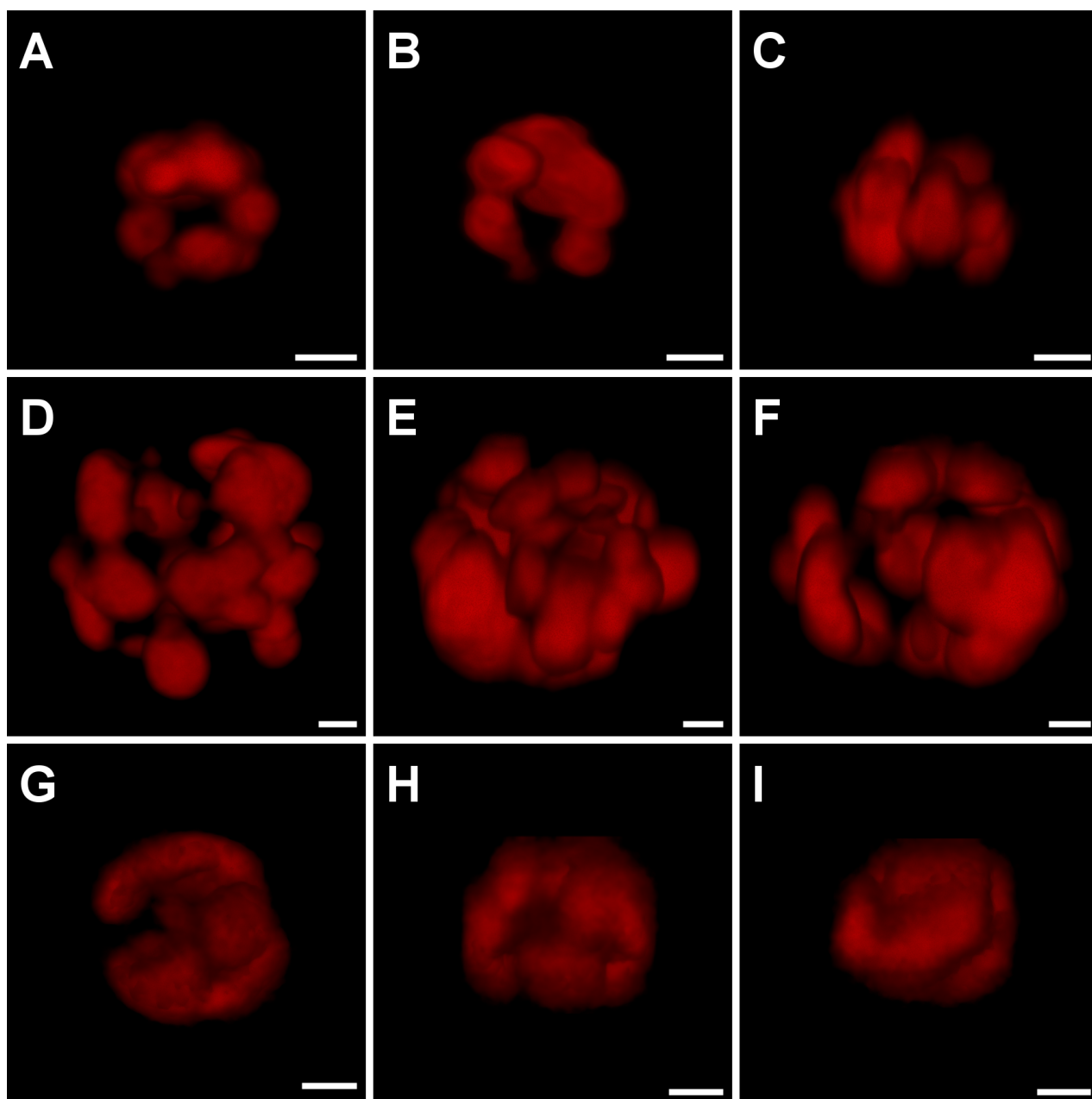


Figure 1: Reconstruction of chloroplasts using CLSM autofluorescence images (Z-stack), views in the direction of the three axes X, Y and Z. *Galdieria daedala* (A-C), *G. maxima* (D-F), *G. partita* (G-I). Scale bar 2 μ m.

empty, lenticular or bag-shaped (both diagnosis and description modified from Sentzova 1991: 73).

Holotypus: NAP, barcode NAP0002464, prepared in 4% formalin from the living strain ACUF 131 from Kunashir Island, and sent O. Ju. Sentzova.

Illustration: Figure 1 (G-I) from the holotype (present study); additional illustrations in Sentzova (1991: 74, figs. «A» 1-14); and in Pinto et al. (2003: 22, Figs. 28-29).

Galdieria phlegrea H.S.Yoon, S.I.Park & Ciniglia, in J. Phycol. 59: 452. 2023.

Type (holotype): No. 02667128 (NY), cells from culture strain 629 S; isotypes at NY (No. 02667129), SKK (No. SKK003972), MABIK (No. MABIK_AL00089919). Illustration: Fig. 2h in Park et al. (2023: 451).

Notes: Claudia Ciniglia can be abbreviated as "Ciniglia", since she is the same author of the invalid name "*Galdieria phlegrea* Pinto, Ciniglia, Cascone & Pollio", in Seckbach, J. (ed.), *Algae and Cyanobact. in extreme environ.*: 501. 2007; Antonino Pollio is wrongly cited in Guiry & Guiry (2023) as "Pollo".

***Galdieria sulphuraria* (Galdieri) Merola** = *Pleurococcus sulphurarius* Galdieri, in Rendiconti Reale Accad. Sci. Fis. Ser. 3, 6: 162. 1899. (basionym). Type (lectotype here designated):-figure [1:] a-i in Galdieri (1899: 161). Epitype (here designated):-NAP, barcode NAP0002465, prepared in 4% formalin and originated from Naples (Italy), Pozzuoli Solfatara.

Galdieria yellowstonensis H.S.Yoon, S.I.Park & T.McDermott, in J. Phycol. 59: 452. 2023. Type (holotype): No. 02667130 (NY), from culture strain HSY245; isotypes at NY (No. 02667131), SKK (No. SKK003973), MABIK (No. MABIK_AL00089918). Illustration: Fig. 2i in Park et al. (2023: 451).

Note: It is not clear if the colonies of *Galdieria* samples at Yellowstone by De Luca et al. (1981, under of *G. sulphuraria*), as well as those cited by Sentzova (1991, under *G. partita*) are to be referred at least partially to this taxon.

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