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New lineages of photobionts in Bolivian lichens expand our knowledge on habitat preferences and distribution of *Asterochloris* algae

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We studied the biodiversity of *Asterochloris* photobionts found in Bolivian lichens to better understand their global spatial distribution and adaptation strategies in the context of a worldwide phylogeny of the genus. Based on nuclear ITS rDNA, the chloroplast *rbc*L gene and the *actin* type I gene we reconstructed a phylogenetic tree that recovered nine new *Asterochloris* lineages, while 32 Bolivian photobiont samples were assigned to 12 previously recognized *Asterochloris* lineages. We also show that some previously discovered *Asterochloris* photobiont species and lineages may occur in a broader spectrum of climatic conditions, and mycobiont species and photobionts may show different preferences along an altitude gradient. To reveal general patterns of of mycobiont specificity towards the photobiont in *Asterochloris*, we tested the influence of climate, altitude, geographical distance and effects of symbiotic partner (mycobiont) at the species level of three genera of lichen forming fungi: *Stereocaulon*, *Cladonia* and *Lepraria*. Further, we compared the specificity of mycobionts towards *Asterochloris* photobionts in cosmopolitan, Neotropical, and Pantropical lichen forming fungi. Interestingly, cosmopolitan species showed the lowest specificity to their photobionts, but also the lowest haplotype diversity. Neotropical and Paleotropical mycobionts, however, were more specific.

Lichens are a marvelous example of ubiquitous, symbiotic fungi. Their thalli contain eukaryotic green algae and/or cyanobacteria, which represent the photosynthetic partners and are called photobionts; however, numerous bacteria and fungi also occur in the lichen symbiosis[1–3]. Many lichens are widely distributed, but it seems that photobionts in lichen symbioses may show their own habitat preferences independent of the lichenized fungus itself[4–6]. Since the organisms' environmental preferences may be closely related to their distribution, the geographical patterns of the photobionts may be different from their fungal partners[5]. Some phylogenetic lineages, species or OTUs (operational taxonomic units), of photobionts are globally distributed, but many photobionts have only been recorded in a specific region or habitat[5,7–9]. In many cases, due to the uneven sampling of the lichen symbionts tested, it is too early to precisely define biogeographic patterns for lichenized algae; this especially applies to photobionts from the tropics[5,7].

Asterochloris is one of the most common photobionts in lichen symbioses, but it is mostly restricted to certain phylogenetic lichen groups, of which undoubtedly the best sampled and studied are these associated with members of *Cladonia*, *Lepraria* and *Stereocaulon*[4,5,9–18]. So far, eighteen species have been identified within *Asterochloris*[13,14,19–22]. Nevertheless, recent research[5,9,14,22,23] demonstrates there are many phylogenetic *Asterochloris* lineages that represent still unrecognized species, which, apart from differences in the molecular markers, also differ in climate and substrate preferences. Moreover, Škaloud et al.[14] indicated that genetic diversity, ecology, biogeography and specificity to mycobiont partners should all be taken into account in species delimitation. In addition, it has been revealed that some lichens usually associated with *Asterochloris* spp. may have additional photobionts in their thalli, e.g., *Chloroidium*[9] or *Vulcanochloris*[9,16].

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