

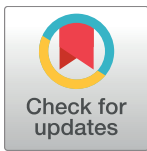
RESEARCH ARTICLE

# Genetic and morphological analyses of *Gracilaria firma* and *G. changii* (Gracilariaceae, Rhodophyta), the commercially important agarophytes in western Pacific

Poh-Kheng Ng<sup>1</sup>, Showe-Mei Lin<sup>1\*</sup>, Phaik-Eem Lim<sup>2\*</sup>, Anicia Q. Hurtado<sup>3</sup>, Siew-Moi Phang<sup>2</sup>, Yoon-Yen Yow<sup>4</sup>, Zhongmin Sun<sup>5</sup>

**1** Institute of Marine Biology, National Taiwan Ocean University, Keelung, Taiwan, R.O.C, **2** Institute of Ocean and Earth Sciences, University of Malaya, Kuala Lumpur, Malaysia, **3** Integrated Services for the Development of Aquaculture and Fisheries (ISDA) Inc., Tabuc Suba, Iloilo City, Philippines, **4** Department of Biological Sciences, School of Science and Technology, Sunway University, Selangor, Malaysia, **5** Laboratory of Marine Organism Taxonomy and Phylogeny, Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China

\* [linism@ntou.edu.tw](mailto:linism@ntou.edu.tw) (SML); [phaikeem@um.edu.my](mailto:phaikeem@um.edu.my) (PEL)



OPEN ACCESS

**Citation:** Ng P-K, Lin S-M, Lim P-E, Hurtado AQ, Phang S-M, Yow Y-Y, et al. (2017) Genetic and morphological analyses of *Gracilaria firma* and *G. changii* (Gracilariaceae, Rhodophyta), the commercially important agarophytes in western Pacific. PLoS ONE 12(7): e0182176. <https://doi.org/10.1371/journal.pone.0182176>

**Editor:** Tzen-Yuh Chiang, National Cheng Kung University, TAIWAN

**Received:** March 31, 2017

**Accepted:** July 13, 2017

**Published:** July 31, 2017

**Copyright:** © 2017 Ng et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Data Availability Statement:** All relevant data are within the paper and its Supporting Information file.

**Funding:** This study was funded by the Taiwan Ministry of Science and Technology (102-2628-B-019-002-MY3 and 105-2811-B-019-004 to SML) and the Ministry of Higher Education, Malaysia, MoHE-HIR Grant (H-50001-00-A000025 to PEL). The Integrated Services for the Development of Aquaculture and Fisheries (ISDA) Inc. did not

## Abstract

Many studies classifying *Gracilaria* species for the exploitation of agarophytes and the development of the agar industry were conducted before the prevalence of molecular tools, resulting in the description of many species based solely on their morphology. *Gracilaria firma* and *G. changii* are among the commercially important agarophytes from the western Pacific; both feature branches with basal constrictions that taper toward acute apices. In this study, we contrasted the morpho-anatomical circumscriptions of the two traditionally described species with molecular data from samples that included representatives of *G. changii* collected from its type locality. Concerted molecular analyses using the *rbcl* and *cox1* gene sequences, coupled with morphological observations of the collections from the western Pacific, revealed no inherent differences to support the treatment of the two entities as distinct taxa. We propose merging *G. changii* (a later synonym) into *G. firma* and recognize *G. firma* based on thallus branches with abrupt basal constrictions that gradually taper toward acute (or sometimes broken) apices, cystocarps consisting of small gonimoblast cells and inconspicuous multinucleate tubular nutritive cells issuing from gonimoblasts extending into the inner pericarp at the cystocarp floor, as well as deep spermatangial conceptacles of the *verrucosa*-type. The validation of specimens under different names as a single genetic species is useful to allow communication and knowledge transfer among groups from different fields. This study also revealed considerably low number of haplotypes and nucleotide diversity with apparent phylogeographic patterns for *G. firma* in the region. Populations from the Philippines and Taiwan were divergent from each other as well as from the populations from Malaysia, Thailand, Singapore and Vietnam. Establishment of baseline data on the genetic diversity of this commercially important agarophyte is relevant in the context of cultivation, as limited genetic diversity may jeopardize the potential for its genetic improvement over time.