

Phylogenetic relationship of *Kappaphycus* Doty and *Eucheuma* J. Agardh (Solieriaceae, Rhodophyta) in Malaysia

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Abstract The genera *Kappaphycus* Doty and *Eucheuma* J. Agardh are important sources of carrageenan in Malaysia, offering lucrative revenues to the carrageenan industry, economy, and the local community. The extensive range of morphotypes and the lack of distinct morphological characteristics led to the application of molecular systematics in elucidating this taxonomic confusion. Local varieties of *Kappaphycus* and *Eucheuma*, identified using putative external morphology, were analyzed using the mitochondrial *cox2–3* spacer and plastid RuBisCO spacer molecular markers. Phylogenetic analysis of these and non-local specimens indicate that *Kappaphycus* and *Eucheuma* are genetically distinct. Three main genotypes of *Kappaphycus alvarezii* were identified, of which two are extant in Hawaii. Morphological and color variations are not supported by molecular data, indicating that most of the local names are not genetically based. Both the *cox2–3* spacer and RuBisCO spacer generated phylogenetic trees with similar topology except in variation of nodal supports. The two markers showed clear separation between *Kappaphycus* and *Eucheuma* and the existence of three Malaysian *Kappaphycus* cultivars. *Cox2–3* spacer data is more variable and provides better resolution than the RuBisCO spacer, showing that *Kappaphycus* is more diversified with a larger number of genotypes, strains, and species which are unique to Southeast Asia. *Kappaphycus* sp. “*Aring-aring*” appeared

to be phenotypically and genotypically different from other *Kappaphycus* congeners, whereas *Kappaphycus striatum* exhibited two different genotypes. Our data indicate that *Eucheuma denticulatum* is the dominant species in Malaysian waters and also suggested paraphyly in *Eucheuma* which will require further studies. The application of molecular taxonomy on Malaysian *Kappaphycus* and *Eucheuma* proves useful, offering valuable insights into the taxonomy and distribution of these commercially important Rhodophytes.

Keywords Algae · Taxonomy · Phylogenetics · *Kappaphycus* · *Eucheuma* · *cox2–3* spacer · RuBisCO spacer

Introduction

The increasing demand for carrageenan has been substantial through the years, contributing to the widespread cultivation of carrageenophytes *Kappaphycus* Doty and *Eucheuma* J. Agardh, particularly throughout paleotropical regions of the world, with the Philippines and Indonesia currently leading in terms of overall *kappa*-carrageenan yield (Bindu and Levine 2010; Bixler and Porse 2010; Phang et al. 2010; Pickering 2006). Mariculture of *Kappaphycus* and *Eucheuma* are generally well studied (Ask and Azanza 2002; Bindu 2010; Gerung and Ohno 1997; Góes and Reis 2011; Hayashi et al. 2007; Hurtado et al. 1996, 2001, 2008; Thirumaran and Anantharaman 2009), albeit cultivation still relies heavily on vegetative propagation of cultivated variants despite efforts to introduce carpospores (Azanza and Ask 2001; Luhan and Sollesta 2010), tetraspore cultures (Bulboa et al. 2007, 2008; Paula et al. 1999) and even hybrids (Cheney et al. 1998).

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