Reviews in Fisheries Science & Aquaculture

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/brfs21

The Diversity of Eucheumatoid Seaweed Cultivars in the Philippines

Richard V. Dumilag, Bea A. Crisostomo, Zae-Zae A. Aguinaldo, Lourie Ann R. Hinaloc, Lawrence M. Liao, Hilly Ann Roa-Quiaoit, Floredel Dangan-Galon, Giuseppe C. Zuccarello, Marie-Laure Guillemin, Juliet Brodie, Elizabeth J. Cottier-Cook & Michael Y. Roleda

To cite this article: Richard V. Dumilag, Bea A. Crisostomo, Zae-Zae A. Aguinaldo, Lourie Ann R. Hinaloc, Lawrence M. Liao, Hilly Ann Roa-Quiaoit, Floredel Dangan-Galon, Giuseppe C. Zuccarello, Marie-Laure Guillemin, Juliet Brodie, Elizabeth J. Cottier-Cook & Michael Y. Roleda (2023) The Diversity of Eucheumatoid Seaweed Cultivars in the Philippines, Reviews in Fisheries Science & Aquaculture, 31:1, 47-65, DOI: 10.1080/23308249.2022.2060038

To link to this article: https://doi.org/10.1080/23308249.2022.2060038

REVIEWS IN FISHERIES SCIENCE & AQUACULTURE
2023, VOL. 31, NO. 1, 47–65
https://doi.org/10.1080/23308249.2022.2060038

REVIEW

The Diversity of Eucheumatoid Seaweed Cultivars in the Philippines

Richard V. Dumilag[a], Bea A. Crisostomo[b], Zae-Zae A. Aguinaldo[b], Lourie Ann R. Hinaloc[b], Lawrence M. Liao[c], Hilly Ann Roa-Quiaoit[d], Floredel Dangan-Galon[e], Giuseppe C. Zuccarello[f], Marie-Laure Guillemin[g,h], Juliet Brodie[i], Elizabeth J. Cottier-Cook[j], and Michael Y. Roleda[b]

[a]Fisheries Department, Sorsogon State University – Magallanes Campus, Magallanes, Sorsogon, Philippines; [b]The Marine Science Institute, College of Science, University of the Philippines, Quezon City, Philippines; [c]Graduate School of Integrated Sciences for Life, Hiroshima University, Higashi-Hiroshima, Japan; [d]Department of Environment and Natural Resources 10, CDO River Basin Management Council, Cagayan de Oro City, Philippines; [e]College of Sciences, Palawan State University, Puerto Princesa City, Palawan, Philippines; [f]School of Biological Sciences, Victoria University of Wellington, Wellington, New Zealand; [g]Instituto de Ciencias Ambientales y Evolutivas, Facultad de Ciencias, Universidad Austral de Chile, Valdivia, Chile; [h]CNRS, Sorbonne Universités, UPMC University Paris VI, UMI 3614, Evolutionary Biology and Ecology of Algae, Station Biologique de Roscoff, Roscoff, France; [i]Department of Life, Sciences, Natural History Museum, London, United Kingdom; [j]Scottish Association for Marine Science, Scottish Marine Institute, Oban, United Kingdom

ABSTRACT
Collectively known as eucheumatoids, *Eucheuma denticulatum*, *Kappaphycus alvarezii*, *K. malesianus*, and *K. striatus* are the main farmed seaweed species in the Philippines. The success of seaweed farming for over five decades in the country is due, in part, to the high diversity of cultivars maintained by the Filipino farmers. Notwithstanding the fact that many eucheumatoid cultivars are presently (and consistently) recognized by the Filipino farmers, there has been no attempt to summarize the current state of the local traditional knowledge about the diversity of this seaweed group, especially with reference to the taxonomy, cultivar designation and distribution. Factors based on present day local knowledge on the eucheumatoid cultivars and what is known on genetic identification in the Philippines were also discussed. A total of 66 cultivars recognized across 58 provinces in the Philippines were documented. Most of these cultivars were morphologically identified as either *K. alvarezii* or *K. striatus,* however, the majority were yet to be genetically identified. In part, due to higher demand of kappa-carrageenan extract as compared from the iota type, *K. alvarezii* and *K. striatus* were widely cultivated in the Philippines than that of *E. denticulatum*. Only in the southern Philippines that *K. malesianus* is currently cultivated. The diverse cultivars identified in this study suggest that the Filipino farmers possess important traditional knowledge that can be useful for future crop selection and breeding.

KEYWORDS
Carrageenophytes; distribution; ethnobotany; seaweed farming; taxonomy

Introduction

The establishment of mariculture economies based upon farmed seaweeds began independently across the globe (Critchley and Ohno 1998). Seaweeds currently comprise a significant portion of the world's aquaculture production, with over 32 million tonnes of fresh weight harvested in 2018 (Chopin and Tacon 2021; FAO 2020). Evolving pressures, based on commercially driven practices, has led to the increase effects of diseases and pests and are compounded by growing environmental challenges (changing climate, pollution, coastal use conflicts, etc.). This brings into question the present farming practices and calls forth the establishment of global surveillance systems to address tradeoffs between climate change and food security (Naylor et al. 2021). Sustainable and high yield production has, however, become a critical factor in the further successful development of this global industry.

The term 'phyconomy' was coined by Hurtado et al. (2019) to describe a unified concept of extensive and sustainable seaweed farming for livelihood purposes. Coupled with economic benefits are the legacies that phyconomy has rendered to human histories, especially on redefining demographics of coastal settle-

CONTACT Richard V. Dumilag richard.dumilag@sorsu.edu.ph Fisheries Department, Sorsogon State University, Magallanes Campus, Aguada Norte, Magallanes, Sorsogon 4705, Philippines

ments (Hussin and Khoso 2021; Nimmo 1986; Nor et al. 2017) and promoting in the industry (Larson et al. 2021; Msuya and Hurtado 2017; Periyasamy et al. 2014; Valderrama et al. 2013). Today, seaweed farming is not only seen as a food crop enterprise, but also as a multi-use system with significant potential for ecosystem services such as carbon capture to mitigate ocean acidification (Duarte et al. 2017; Froehlich et al. 2019; Xiao et al. 2021), aid in eutrophic environment restoration (Narvarte et al. 2022; Roleda and Hurd 2019) and provide an eco-engineering solution for problems on urban shorelines (Heery et al. 2020).

Species belonging to the rhodophyte genera *Kappaphycus* and *Eucheuma*, collectively known as eucheumatoids, are the major sources of carrageenans. Carrageenans are commonly used as processed food ingredients. The various types of carrageenans are composed of high molecular weight sulfated hydrocolloid molecules that are added to other foods as gelling, thickening, and stabilizing agents (Guo et al. 2022). Some of the physical properties of carrageenans have been used recently as effective encapsulating agents (Dong et al. 2021; Jana et al. 2022), and for anti-viral properties (Derby et al. 2018; Jang et al. 2021). Evidence imposing health risks of carrageenans have however rendered moot about the confusion between poligeenan (a possible human carcinogen) with native carrageenans and the modes of the administration used (Bhattacharyya et al. 2019; David et al. 2018; McKim et al. 2019). The huge database around the use and benefits of carrageenans will certainly continue to drive path to the success of providing unique solutions to various human use, particularly in health promotion (Frediansyah 2021; Jayakody et al. 2022; Liu et al. 2021).

The eucheumatoids were in part, initially cultivated in the Philippines to support a carrageenan industry suffering from decline in wild collections, and to produce more stable and uniform product (Blanchetti-Revelli 1995; Kraft 1997). Selection of fast-growing clones of eucheumatoids form wild stocks by pioneering Filipino farmers (Doty and Alvarez 1975) and the successful establishment of farms in the 1970s led to the rapid adoption and expansion of seaweed farming in the Philippines (Trono and Largo 2019, see also Figure 1). There are currently 58 coastal provinces engaged in seaweed farming in the country (Figure 1). Local and seasonal changes in environmental conditions (e.g. seasonal typhoons) and farming problems (e.g. diseases and pests) can influence crop production and as a result, a number of local farming customs have been developed including selection of cultivars (i.e. after exchange of cultivars between the Filipino farmers), cropping calendars (i.e. selecting growing season and harvesting time to maximize production), type of planting and drying methods (Hurtado et al. 2019; Quiaoit et al. 2016).

Seaweed cultivar traits are either preexisting (from their evolutionary history) or have arisen during the domestication process through breeding and artificial selection (Valero et al. 2017). Deliberate or unintentional artificial selection may drive the ability of cultivars to improve or maintain high productivity despite varying environments (Charrier et al. 2015; Hwang et al. 2019; Kluyver et al. 2017). The selected eucheumatoid cultivars typically exhibit traits that favor high biomass production and qualities, such as carrageenan yield and gel strength (Parenrengi et al. 2020; Phang et al. 2010; Trono et al. 2000). The cultivation in eucheumatoids is done through asexual or vegetative propagation. There is no breeding (as in sexual crosses) ever done, however rare reports of sexually reproductive individuals were observed at farm sites (see Azanza-Corrales et al. 1992). Farmers may have been long selecting introgressed individuals unintentionally, allowing combinations of superior eucheumatoid cultivars.

It has been suggested that a classification system based on the information imparted by the farmers can serve as a starting point for assessing the diversity of crop cultivars, such as observed in maize (Hopkins 2006), potato (de Haan et al. 2007), rice (Loko et al. 2021; Wang et al. 2016), banana (Chabi et al. 2018; Nantale et al. 2008) and yam (Asfaw et al. 2021). For eucheumatoid cultivars, improving knowledge on genetic and phenotypic diversity could help identify suitable candidates for strain amelioration and increase resiliency to disease or pest outbreaks, and to multiple stressor effects associated to climate change (Faisan et al. 2021; Hinaloc and Roleda 2021; Largo et al. 2017; Ward et al. 2020, 2022). The innate effectiveness of seaweed cultivars in terms of production is demonstrably enhanced when combined with other means of improving pathogen control and thermal tolerance such as DNA fingerprinting, genetic assessment, hybridization and thermal priming (Hu et al. 2021; Hwang et al. 2019; Jueterbock et al. 2021). Knowledge on farming practices and the diversity of cultivars, in combination with the application of breeding programs, can be used as a valuable reference in national planning initiatives in providing effective policy frameworks to sustainably develop the industry (Brakel et al. 2021; Cottier-Cook et al. 2016).

The seaweed cultivars initially identified for commercial exploitation in the Philippines (Doty 1973; Doty and Alvarez 1973; Parker 1974) have now been distributed worldwide, due to easy vegetative

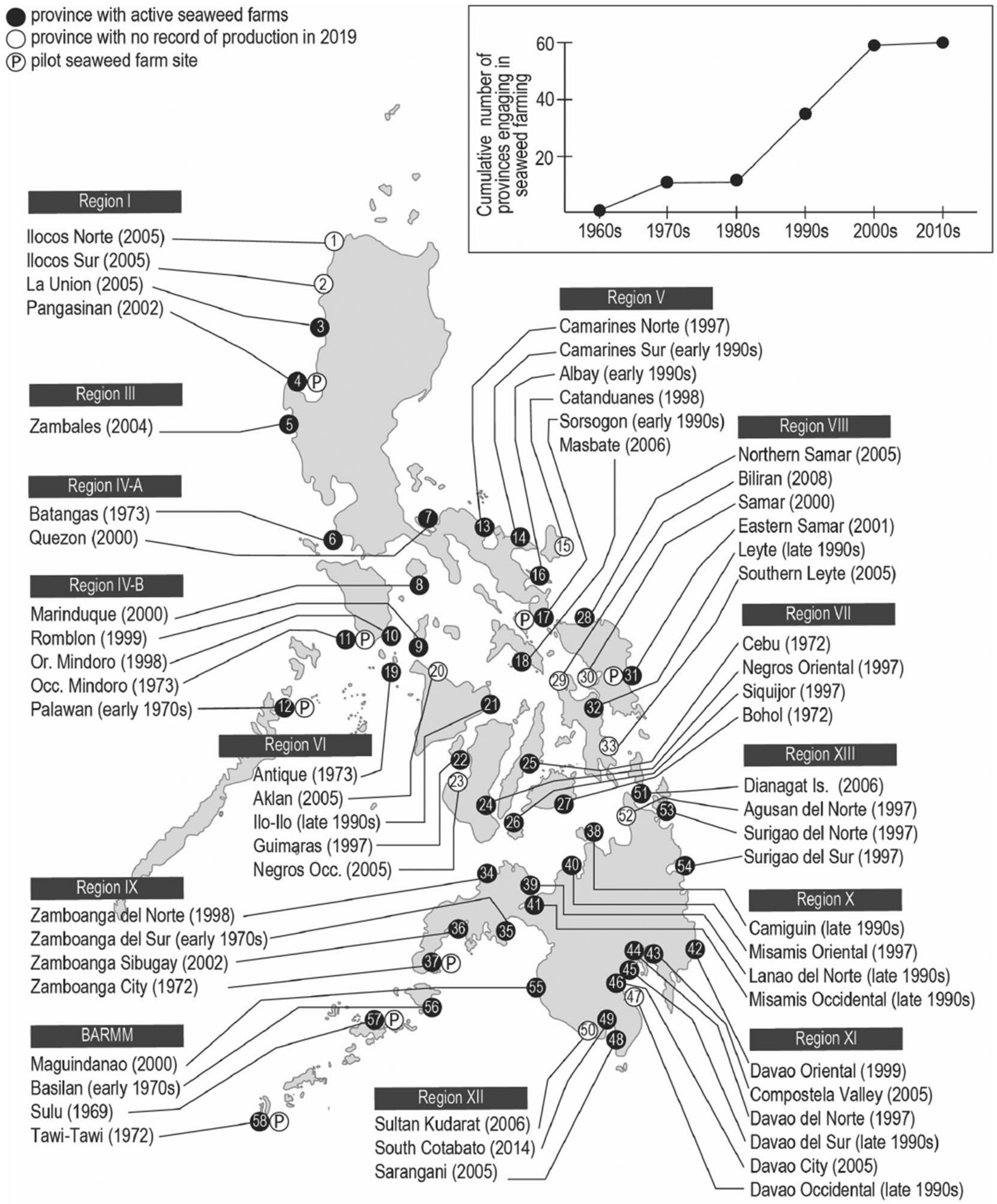

Figure 1. Distribution of seaweed eucheumatoid farms in the Philippines. The cumulative number of provinces in the Philippines engaging in seaweed farming has increased since its inception in the late 1960s (inset).

propagation (Kelly et al. 2020; Neish et al. 2017). From over the five decades of seaweed farming, Filipino farmers have accumulated extensive knowledge on farming practices and cultivar selection (Mateo et al. 2021; Suyo et al. 2021). Despite the long history of seaweed farming in the Philippines, the diversity, and distribution of seaweed cultivars as recognized locally in the country have not been thoroughly reviewed. The current contribution aims to review the taxonomy, diversity, and distribution of eucheumatoid cultivars, as well as their genetic differentiation and conservation strategies in the Philippines.

Literature review

A systematic review was conducted of peer-reviewed journal articles, local books, and unpublished lists that mention local names of eucheumatoid cultivars identified by the Filipino farmers. Species identification of these cultivars were determined by either consulting the farmers directly or, if previously reported, by assessing the original reporting sources. The cultivars were identified based on the species recognized by each of the sourced authors, local names that were used by other authors to refer to a similar cultivar name, cultivar name etymologies, and their distribution in the Philippines. Translation and interpretation of the meanings of the local names were provided by the farmers or expert native speakers. The reported *cox*2-3 spacer barcodes of eucheumatoids from the Philippines were also gathered from existing literature.

Nomenclatural note

The terms *cultivar*, *strain*, and *variety* are commonly used interchangeably in differentiating morphological diversities among algae, particularly in seaweed crops. The term *strain* may either refer to a wild or cultivated eucheumatoid. The name of a strain can be derived from a name used by the farmers, or a name assigned by the investigator (e.g. on the basis of a replicate) generally used for experimental studies (see Ali et al. 2018; Hayashi et al. 2007; Mendoza et al. 2002). In this review, only the term *cultivar* will be used to the seaweed crops grown and named by the farmers in accord with the definition of the International Code of Nomenclature for Cultivated Plants (Brickell et al. 2016). Likewise, as specified in the International Code of Nomenclature for Algae, Fungi, and Plants (Turland et al. 2018), the use of the term *variety* in this study will pertain to a variation below species level effected by a valid taxonomic description.

Taxonomy of eucheumatoid seaweed cultivars in the Philippines

Eucheumatoid seaweeds (tribe Eucheumatoideae, family Solieriaceae, order Gigartinales, phylum Rhodophyta) represent the majority of farmed species in the Philippines (Doty 1988). The tribe Eucheumatoideae originally contained three genera: *Eucheuma*, *Kappaphycus*, and *Betaphycus* (Doty 1988, 1995). Recent phylogenomic reconstruction based on 21 mitochondrial genomes suggests that the three genera form a clade (Li et al. 2018). Current molecular phylogenetic analyses inferred within the Eucheumatoideae has now led to the addition of three more genera, *Tacanoosca* (Norris 2014), *Eucheumatopsis* (Núñez-Resendiz et al. 2019), and *Mimica* (Santiañez and Wynne 2020), each segregated from *Eucheuma sensu lato*.

Although phylogenetic radiation within the tribe has been hypothesized to have occurred in the ancient Tethys Ocean prior to continental shifts some 100 MYA (Fredericq et al. 1999), the highest eucheumatoid diversity is currently reported in the Indo-Pacific (Doty 1988; Hurtado et al. 2016). Members of the eucheumatoids are found growing in a variety of habitats from shallow reefs to depths of over 45 m (Doty 1973). As a consequence of intentional transplantations that have taken place for farming uses, eucheumatoids are also now established in many non-indigenous regions characterized by warm waters of Atlantic (Brakel et al. 2021; Kelly et al. 2020).

The farmed eucheumatoids in the Philippines include *Eucheuma denticulatum*, *Kappaphycus alvarezii, Kappaphycus malesianus,* and *Kapppahycus striatus* (Figures 2 and 3). Morphologically, these taxa are characterized by a set of several overlapping characters (Doty 1988; Hurtado et al. 2016; Tan et al. 2014) that make definitive identification difficult at times. Progress on the phylogeny and taxonomy in this group has been enhanced by the use of molecular data (Dumilag et al. 2016a; Lim et al. 2017; Tan et al. 2012; Zuccarello et al. 2006). Despite the considerable morphological diversity that domesticated eucheumatoids display, there are only four taxonomic varieties recognized. These include *Eucheuma denticulatum* var. *endong* (Ganzon-Fortes et al. 2012), *Kappaphycus alvarezii* var. *alvarezii*, *Kappaphycus alvarezii* var. *tambalangii* and *Kappaphycus alvarezii* var. *ajakii-assii* (Liao 1996). Except for *K. alvarezii* var. *alvarezii* (type locality is in Malaysia), the Philippines is the type locality of all these varieties (Doty 1985).

Commercial nomenclature in eucheumatoids

Far predating the advent of their domestication, the use of seaweeds as food in the Philippines has a history dating back to pre-colonial occupation of the islands (Velasquez 1977). The earliest Philippine record of seaweed as a trade commodity began in the seventeenth century when *Agal-agal*, a local name for eucheumatoids, was recorded as a major food product (dried and fresh seaweeds) in the early Sulu enterprises and as an exchange commodity for imports from China (Fry 1970; Saleeby 1908). In 1704, Georg Joseph Kamel, S.J., the Jesuit missionary and apothecary based in Manila, mentioned an abundant marine commodity locally called *goso* which undoubtedly referred to various eucheumatoids back then as well as now (Liao 2013). Eucheumatoids have since remained a highly sought after seaweed products, with deep cultural value among communities in the Philippines (Dumilag 2019).

Stable nomenclature for products is necessary for communication and record keeping regarding

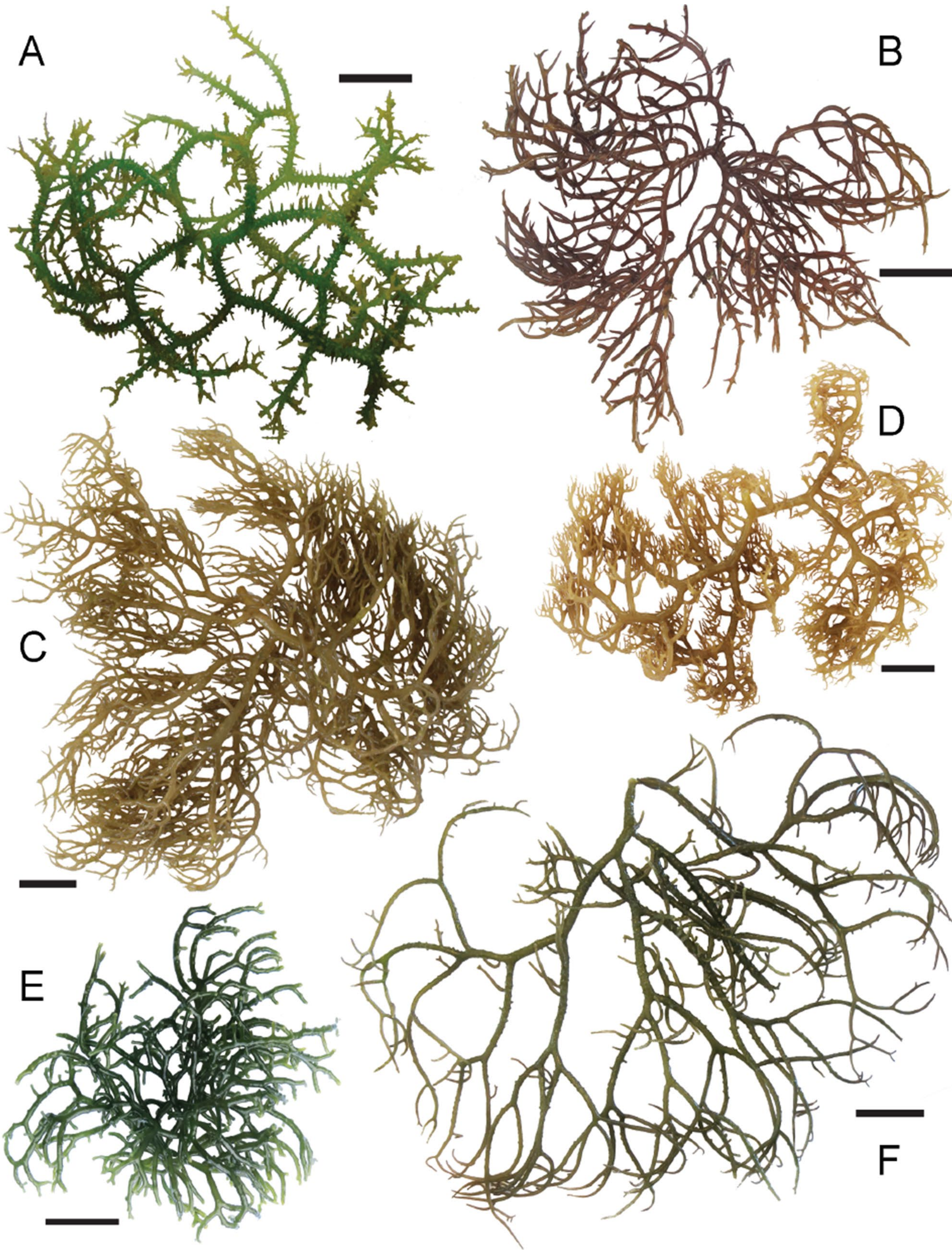

Figure 2. Philippine *E. denticulatum* and *K. alvarezii* cultivars. *E. denticulatum* cultivars *Spinosum* (A) from Cebu and *Milyon-Milyon* (B) from Batangas. *K. alvarezii* cultivars *Tambalang* (C) and *Marimar* (D) from Tawi-Tawi, *Digos* (E) and *Giant* (F) from Surigao del Sur. Scale bars: A: 5 cm, B: 3 cm, C: 5 cm, D: 3 cm, E: 3 cm, F: 12 cm.

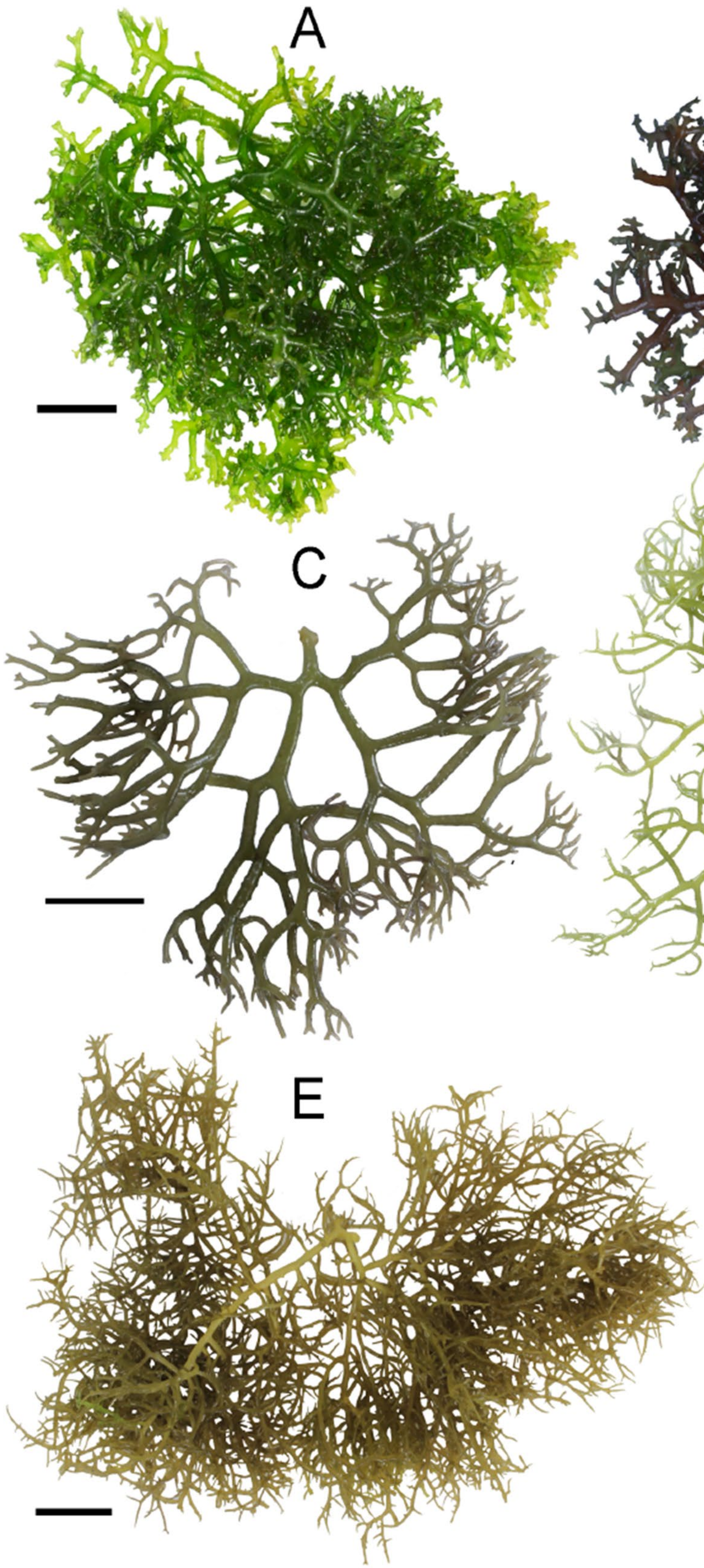

Figure 3. Philippine *K. striatus* and *K. malesianus* cultivars. *K. striatus* cultivars Sacol (A) from Batangas, *Seven Colors* (B) from Tawi-Tawi, *Kab-Kab* (C) from Zamboanga City. *K. malesianus* cultivars *Aring-Aring* (D), *Halaw* (E) and *Kuku Belleh'* (F) from Tawi-Tawi. Scale bars: A: 3 cm, B: 3 cm, C: 5 cm, D: 3 cm, E: 3 cm, F: 6 cm.

biological resources and their acceptance for trading purposes. The standard use of names is also essential to various scientific applications as there can be mixing of eucheumatoid species belonging to different genera. This leads to mixed carrageenan extracts, lowering the quality of the final product (see Ganzon-Fortes et al. 2012). Since the 1980s, taxonomists have been aware of the significant confusion that exists in relation to the correct scientific epithets for commercially important seaweeds (Bolton 2020), including of eucheumatoids (Dumilag et al. 2020, Table 1). The situation is compounded in eucheumatoids, as some investigators continue to publish their work using outdated nomenclature, e.g. the use of "*Eucheuma cottonii*" (see Mansa et al. 2013; Matanjun et al. 2009; Purbosari et al. 2021 Surya et al. 2021; Teo et al. 2021), "*Eucheuma spinosum*" (see Bouanati et al. 2020, Gurav et al. 2021) and even a non-existent taxonomic combination, "*Kappaphycus spinosum*" (see Adharini et al. 2019). This highlights the importance of proactive assessment and intervention by journal editors and expert reviewers, particularly in applied sciences where reports of invalid species names are prevalent (c.f. Roleda et al. 2021b; Roleda and Heesch 2021) and are most often left uncorrected, except on rare occasions (e.g. Roleda et al. 2021c).

Diversity of Philippine eucheumatoid cultivars based on local knowledge

Sixty-six eucheumatoid cultivars were identified and named in the Philippines, largely based on morphology recognized by Filipino farmers (Table 2). Twenty-seven cultivars were identified as *K. alvarezii,* 15 as *K. striatus*, six as *E. denticulatum* and three as *K. malesianus*. Fifteen cultivar names required further investigation to determine what species they belong to. The majority (83%) of cultivar names were identified as a single species while others were attributed to more than one taxa. For example, the cultivar *Aring-Aring* was represented by all three farmed *Kappaphycus* species while the cultivars *Cottonii* (or *Katunay*) and *Sacol* may be attributed to either *K. alvarezii* or *K. striatus*. Even the *Spinosum*, the most common cultivar name for *E. denticulatum*, can be referred to as a cultivar of *K. alvarezii* (Table 2).

Local cultivars were structurally named, using either a unitary (single word) or a binary (two words) format. Unitary names predominated, constituting 62 of the 66 cultivars identified by farmers. Of these, 83% were derived from local dialects, while the others were adapted from English. Some unitary names were formed through full lexical reduplication (i.e. repeating names such as *Milyon-Milyon*, *Kab-Kab*, *Butay-Butay*), a familiar word formation process among Philippine language (Blake 1917; Mattes 2014; Rubino 2005). With the exception of the cultivars *Ara Mina* and *Kuku Belleh*', the others had binary names adapted from English (e.g. *Nile Green, Sweet Loving* and *Seven Colors*).

The translation of the names used revealed that most cultivar names matched certain aspects of the seaweed. The name derivations were based on several attributes, or objects, such as the description of the general branching pattern (e.g. *Endong* is a worm-like, *Kab-Kab* is a fan-like, and *Repolyo* is a cauliflower-like), color (e.g. *Nile Green*, *Pula-Pula* [red], and *Seven Colors*), source locality (e.g. *Digos*, *Sacol*, and *Zamboanga*) and the person who discovered them (e.g. *Aring-Aring* and *Tambalang*). Only a few names had no clear reference as to the characteristics or history of the origin, e.g. some cultivars were named from popular personalities (e.g. *Ara Mina* and *Marimar,* popular actresses), or random brand names (e.g. *Duralex, Bitsi-Bitsi* from Mitsubishi, and *Vanguard,* brand names relating to boats). Two cultivars have unknown etymologies (i.e. *Sweet Loving* and *Way-Way*).

Eighteen cultivars had variant names (Table 2). The cultivar *Tambalang* (Figure 3C) had the greatest number of variants with 14 name combinations. Color was the most common trait attributed to a variant name (see also Hurtado 2013). Brown, green, and red were found to be the dominant colors of seaweed cultivars in the Philippines (Figure 4). The species

Table 1. Commercial names of farmed eucheumatoid species in the Philippines.

Extracted carrageenan	Commercial name	Taxonomic name		Commonly confused species name
		Curently accepted species	Common Synonym	
beta-carrageenan	serra	*Betaphycus gelatinus*	*Eucheuma gelatinae* *Betaphycus gelatinum* *Betaphycus philippinensis*	*Eucheuma serra*[1*] *Eucheuma perplexum*[1*]
iota-carrageenan	spinosum	*Eucheuma denticulatum*	*Eucheuma spinosum*	*Eucheuma serra*
kappa-carrageenan	cottonii	*Kappaphycus alvarezii* *Kappaphycus malesianus* *Kappaphycus striatus*	*Eucheuma alvarezii* *Eucheuma striatum*	*Kappaphycus cottonii*[2] (as *Eucheuma cottonii*)

Non-domesticated eucheumatoid species producing [1]iota- or [2]kappa-carrageenan. See details on Dumilag et al. (2020).

Table 2. A list of eucheumatoid cultivars identified and named by Filipino farmers, including their etymology, *cox* 2-3 spacer haplotype assignment and distribution.

Local Name (variant)	Etymology (dialect)	*cox*2-3 spacer haplotype	Philippine distribution
E. denticulatum			
Endong, Spaghetti (br, gr)	worm-like (Sama)		17[a], 27[b], 58[b]
Korea	as the country		37[c]
Spinosum (br, gr)	spinous morphology	13[d]	5[b], 6 [b], 10 [b], 12 [b], 17 [b], 18 [b], 19 [b], 21 [b], 22 [b], 24 [b], 25 [b], **27**[d], 28 [b], 32 [b], 33 [b], 36 [b], 37 [b], 42 [b], 45 [b], 46 [b], 51 [b], 54 [b], 57 [b], 58 [b]
Milyon-Milyon	presence of numerous branches (Tagalog, derived from the English word million)		6[b], 11[b], 12[b], 19[b], 22[b], 27[b], 37[b]
Nile green	refers to its color		45[b], 48[b], 47 [b]
Zamboanga	the province of its origin, Zamboanga		54[b]
K. alvarezii			
Adik-Adik /Adis-Adis (br, gr, rd)	refers to a junkie, a drug addict (Bisayan pop culture)		35[b], 37[b,e,f], 45[b], 46[b]
Aring-Aring (br, gr)	after Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi	3[g]	**17**[g], 58[c]
Barako	boar, related to a local coffee from Batangas, origin may be from this area (Tagalog)	3[h]	**22**[b,h]
Bermuda	refers to its color, Bermuda green	3[h]	42[b], 53[b], **54**[b,h]
Burikat (br, gr)	to open one's legs wide (Bisaya)	KALV-1 (br)[h] KALV-2 (gr)[h]	35[b], **54**[h]
Cottonii, Katunay (br, gr)	named after Arthur Disbrowe Cotton, an English botanist who supplied Anna Antoinette Weber van Bosse the specimens used to describe *Kappaphycus cottonii* – katunay is an onomatopoeaic form of 'cottonii'	3[d]	4[b], 5[b], 7[b], 13[b], 18[b], 17[b], 19[b], 22[b], 25[b], **27**[b,d], 28[b], 31[b], 34[b], 35[b], 36[b], 37[b], 42[b], 44[b], 45[b], 53[b], 54[b], 57[b], 58[c]
Digos (br, gr)	its area of origin, Digos City, Davao del Sur	3[h]	**54**[h]
Giant (kapilaran, original)	pertains to its large size	3[h] KALV-1[h]	12[b], **25**[f], 28[b], 31[b], 32[b], 33[b], 34[b], 35[b], 36[b], 37 [b,f], 53[b], **54**[b,h], 58 [b,h]
Gulaman	anything jelly (Tagalog)		18[b], 30[b], 31[b]
Jackpot, Swerte	lucky (English, Spanish)		58[b]
Kab-Kab, Pay-Pay	fan-like (Tausug)	3[d]	35[b], **37**[d], 58[b]
Kinangkong, Natural, Plastic	water spinach-like, vegetable-like (Tagalog)		13[b], 14[b]
Kinse-Kinse	refers to fifteen days before harvest (Spanish 'quince')		11[b], 12[b], 58[c]
Kulot	curly (Tagalog)		37[b], 58[c]
Lakway	from 'lakaw' means to walk (Bisaya)		43[b], 44[b], 54[b]
Marimar	a famous 1990s Mexican soap opera released in the Philippines under the same title	3[h]	58[h]
Milo-Milo, Milo	a popular brand of cocoa drink, referring to its branch color	3[i]	35[b], **37**[i], 58[b]
Patig	from 'fatigue', a khaki-olive green military suit		58[c]
Pula-Pula	red (Tagalog, Bisaya)		58[c]
Putan	from the same name of a Sama local sticky rice cake. Its brown color matches that of the cultivar's branches (Tausug)		58[c]
Tambalang (abu [gy], adik, batu [rock], br, diki [small], giant, heya [big], milo, monten [mountain], pu, lapsi, rd, sacol, tunay [shortened from Katunay])	derived from the owner of the farm, Mr. Tambalang Bin Panggian from Sitangkai	3[d]	6[b], 7[b], 12[b], 14[b], 16[b],18[b], 22[b], **25**[h], 35[b], **37**[h], 40[b], 42[b], 43[b], 44[b], 45[b], 46[b], 47[b], 48[b], 57[b], **58**[b,c,d,]
Tungawan	a municipality in Zamboanga Sibugay		22[j]
Spinosum (br, gr)	spinous morphology	3[h]	54[h]
Sweet Loving	unknown etymology		58[b]
Sacol (rd, vanguard)	an island in Zamboanga City	3[d]	12[c], **37**[d,k]
Vanguard	from the brand name of the machine, Vanguard, bought by a seaweed farmer after his good harvest	3[d]	**37**[d]
Way-Way	unknown entity		39[b], 41[b], 36[b],
K. malesianus			
Aring-Aring	from Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi		58[b]
Halaw	illegal Filipino deportees to borders of Malaysia (Tausug/Sama)	MY216[h]	**58**[h]
Kuku Belleh'	talon of an eagle (Sama)	MY216[h]	**58**[h]

(*Continued*)

Table 2. (Continued)

Local Name (variant)	Etymology (dialect)	*cox*2-3 spacer haplotype	Philippine distribution
K. striatus			
Aring-Aring (br, gr)	from Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi	89[g]	**17**[g]
Bitsi-Bitsi, Bitsi (gr)	from the corrupted name of a boat engine brand, Mitsubishi	89[h]	**58**[h]
Bola-Bola	ball-like (Tagalog)		25[b], 28[b]
Bukoy-Bukoy	a name of a child, presumably from Palawan		12[b,c]
Cottonii, Katunay (bl, br, gr, rd, sacol)	named after Arthur Disbrowe Cotton, an English botanist who supplied Anna Antoinette Weber van Bosse the specimens used to describe *Kappaphycus cottonii*	89[d]	17[b], 22[b], **27**[b,d], 57[b], **58**[b,d]
Duyan-Duyan (br, gr, rd)	hammock-like (Tagalog)		48[b], 57[b], 58[b]
Emo (br, gr)	presumably a name of a farmer who first used it from Zamboanga, Mr. Emo	89[h]	**37**[h]
Jackpot, Swerte	lucky (English, Spanish)	89[h]	**58**[h]
Jayan-Jayan	giant-like, an onomatopoetic form of 'giant' from English		58[c]
Kab-Kab, Paypay (br, gr)	fan-like (Tausug/Sama, Tagalog, Bisaya)	89 (gr)[h], 117 (br)[h]	35[b], **58**[b,d,h]
Payaka, Yaka	squatting posture or form (Bisaya)		25[b], 32[b], 53[b]
Sacol, Cauliflower, Flower, Repolyo (br, gr, or)	the area of its origin, Sacol Is., Zamboanga, cabbage-like (Tagalog)	89[d,h]	**6**[b,h], 12[b], 17[b], 19[b], 21[b], **22**[b,h], 25[b], 28[b], 35[b], **37**[b,d,h,f], 53 [b], 57[b]
Seven Colors	pertains to the seven colors of its branches		58[b,c]
Subul/Subol-Subol (br, gr, rd)	a young male (Tausug)		58[c]
Vanguard, Banggard	derived from the name of a boat engine brand; Banggard is a spelling variant of Vanguard	89[h]	5[b], 11[b], 12[b], 18[b], 25[b], 27[b], 28[b], 34[b], 35[b], 39[b], 41[b], 53[b], **58**[b,h]
Unknown species			
Ara Mina	screen name of Hazel Pascual Reyes, a popular Philippine actress		36[b], 37[b]
Bisaya	the local people from Visayas region		27[k]
Bulawan	golden (Tausug, Bisaya)		12[b]
Butay-Butay	like a coconut leaf midrib (Cebuano)		27[b]
Dayang-Dayang	a princess (Tausug/Sama)		25[b]
Dugong	*Dugong dugon,* the sirenian		43[b], 44[b]
Duralex	from the corrupted name of a marine paint brand, Duralux		35[b]
Durian	from *Durio zibethinus*, the strongly aromatic fruit in SE Asia		58[b,c]
Marlin	a fish belonging to family Istiophoridae		37[l]
Original	originally sourced from Antique province only		19[b]
Polotan	any food eaten without rice (Tagalog)		35[b]
Sakot	ingredient (Bisaya)		19[b]
Sparkle	pertaining to its green color		58[c]
Sprite	a popular soft drink brand, inspired by the similar green color of its bottle		12[b]
Tangtang-utang	literally dropping of debt (Bisaya)		37[c]

bold numbers indicate site of collection of DNA barcoded specimen/s.
bl: black, br: brown, gr: green, gy: gray, or: orange, pu: purple, rd: red.
[a]Ganzon-Fortes et al. 2012.
[b]Quiaoit et al. 2016.
[c]This study.
[d]Lim et al. 2014.
[e]Hurtado and Biter 2007.
[f]Hurtado et al. 2009.
[g]Dumilag and Lluisma 2014.
[h]Dumilag et al. 2016a.
[i]Tan et al. 2012.
[k]Borlongan et al. 2011.
[k]Hurtado 2013.
[l]Suyo et al. 2020.

with most color variability was *K. striatus*. Several individuals of the *E. denticulatum* cultivar *Spinosum* (Figure 2A) exhibited bi-colored (brown and red) thalli. This similar color pattern was observed in specimens (referred to as ecotypes) sampled from varying environments suggest that it may have a genetic basis, as previously shown in gracilarioids (e.g. Marchi and Plastino 2020; Plastino et al. 1999; van der Meer 1979). Accordingly, the green and brown color variants of *K. alvarezii* cultivar *Burikat* and *K. striatus* cultivar *Kab-Kab* (Figure 3C) each had differing *cox*2-3 spacer haplotypes (Dumilag et al. 2016a, see Table 2). Mention of variation in pigmentation was rare in eucheumatoid cultivars while this type of trait

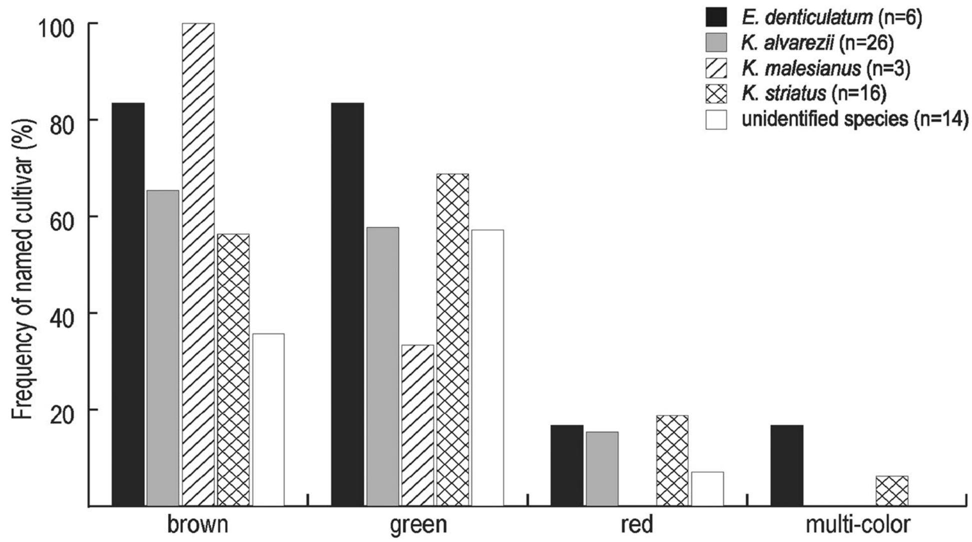

Figure 4. Percentage frequency of seaweed cultivars corresponding to their thallus color. The number of identified cultivars (n) is denoted per species.

was important in the description for some cultivars. Accordingly, the *K. striatus* cultivar *Seven Colors* (only recorded in Tawi-Tawi, southern Philippines to date, see Figure 3B) cannot be categorized as one discrete color, since the thallus was multi-colored ranging from yellow, to green to brown. If other cultivars had exhibited pigment variation comparable to *Seven Colors*, seaweed farmers would probably have used it as a distinguishing character. Other variant identification features were based on a combination of other cultivar names, e.g. *Tambalang Giant, Tambalang Sacol, Sacol Vanguard* or size differences, e.g. *Tambalang diki* (small) and*Tambalang heya* (big).

The basis behind the pigment expression in eucheumatoids is not well understood. Recently, wild reproductive *K. alvarezii* (cystocarpic and tetrasporic) were observed to exhibit mosaic pigmentation on the same branch. The resulting tetrasporophyte progeny expressed the same mosaic pigmentation as their parent, while the gametophyte progeny expressed different colors (Hinaloc and Roleda 2021). Expression of mosaic pattern of pigmentation in eucheumatoids may have resulted from the coalescence of "genetically-distinct" spores (chimeric plants) as reported in *Gracilaria chilensis* (Santelices et al. 2017) and *Neopyropia yezoensis* (Niwa and Abe 2012).

Distribution of eucheumatoid cultivars in the Philippines

The eucheumatoid species and the corresponding distribution of cultivars in the Philippines appeared to be random (Figure 5, Table 2). Twenty-six of the named cultivars were recorded in multiple areas throughout the country. Forty cultivars were exclusive to a single area, particularly in Regions IX and XIII, and BARMM. The highest number of cultivars were found within the larger farming areas, including Tawi-Tawi (BARMM, n = 30), Zamboanga City and Zamboanga del Sur (Region IX, n = 17 and n = 12 respectively), and Palawan (Region IV-B, n = 11). The cultivar named *Spinosum* (Figure 2A) was found to be the most widely distributed of the *E. denticulatum.* The *Cottonii*, *Tambalang* (Figure 2C) and *Giant* (Figure 2F) accounted for the three most common *K. alvarezii* cultivars. *Sacol* (Figure 3A) and *Vanguard* were the most common for *K. striatus*. Only being reported in Tawi-Tawi, *K. malesianus* had the most restricted distribution. It had three locally recognized cultivars namely *Aring-Aring* (Figure 3D), *Halaw* (Figure 3E), *Kuku Belleh*' (Figure 3F). Nearly all of those cultivars that have yet to be identified by scientific names are only known from their respective areas, mostly from southern Mindanao.

Selection of eucheumatoid cultivars in the Philippines is most often related to the type of carrageenan, robustness (against environmental stressors, pest, and disease) and high productivity or growth rate, while other specific cultivar properties (e.g. color or branching pattern), may be nugatory to the farmers. The wide distribution of farmed *K. alvarezii* and *K. striatus* in the Philippines is due to the higher demand kappa-carrageenan extracts (i.e. as opposed to iota type carrageenan) and their reputations for greater environmental tolerance (Bindu and Levine 2011; Glenn and Doty 1992). The widespread use of cultivar names, e.g.

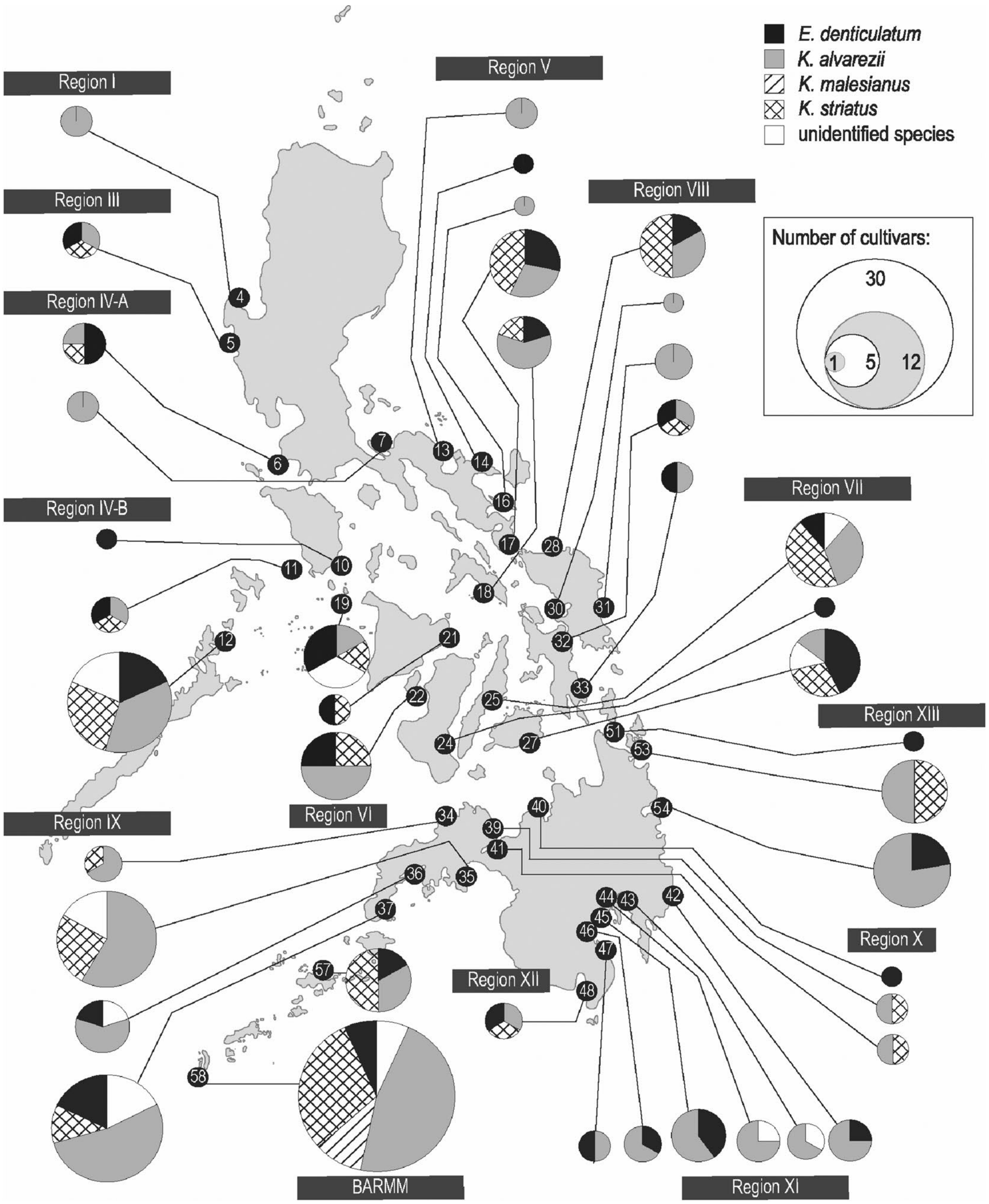

Figure 5. Distribution of seaweed cultivars in the Philippines. Pie chart represents eucheumatoid species grown by farmers per province grouped by political region in the Philippines. Numbers indicate provinces shown in Figure 1.

Spinosum, *Tambalang*, and *Cottonii*, was most likely related to the free exchange of seedstocks across the country (see Quiaoit et al. 2016). Reciprocal transfers of cultivars was found to follow traditional community practice, as exchange occurred primarily between relatives, friends, or neighbors usually within similar ethnic groups (R. Dumilag, personal observation). Seedstocks were also exchanged after loss of crops (e.g. by typhoons or diseases and pests), during farm expansion, or when testing other cultivars for greater yields. It is therefore possible that the same cultivar names have been given to distinct farmed genotypes in different areas. Genetic diversity is not seen by the farmers while morphological diversity may not represent genetic diversity. The information based on local knowledge may also underestimate the morphological and genetic diversity at the national, or regional level (as in case study in yam by Asfaw et al. 2021).

Typhoons are among the most severe natural disturbances seaweed farms in the Philippines ever face, i.e., rendering greatest production penalties and upsetting the dynamics of local livelihoods (Andriesse and Lee 2017). The government interventions play an important role in the supply of seedstocks among farmers, particularly after the typhoons (Cuaton 2019; Suyo et al. 2021). Farmers receive seaweed cultivars for free from the government agencies such the Department of Science and Technology (DOST), Bureau of Fisheries and Aquatic Resources (BFAR), Department of Trade and Industry (DTI) and the respective local government units (Quiaoit et al. 2016). Indonesia has overtaken the Philippines in eucheumatoid production since 2008 (Bixler and Porse 2011). In part, this is due to the frequent exposure of the Philippines to typhoons.

Genetic diversity of Philippine eucheumatoid cultivars

Information on genetic diversity among Philippine seaweed cultivars is still incomplete, with only 25 cultivars sequenced for mitochondrial markers. The most recent analysis based on the *cox*2-3 spacer revealed that Philippine cultivars include seven haplotypes (Roleda et al. 2021a). A survey of mitochondrial *cox*2-3 spacer sequences revealed between one to three farmed haplotypes per species: *E. denticulatum* (haplotype 13), *K. alvarezii* (haplotypes 3, KALV-1 and KALV-2), *K. malesianus* (haplotype MY216), and *K. striatus* (haplotypes 89 and 117). There were no clear correspondences between mitochondrial haplotypes, morphology, and cultivar names. Notwithstanding, this apparently high genetic similarity and lack of concordance between haplotypes and phenotypes, the morphological features of the different cultivars still allowed differentiation. The morphological differences also appeared to be fairly stable or were conserved between different environmental conditions, which explained how farmers were able to visually recognize each type of cultivar in the field. This observable phenotypic diversity raises the possibility that more informative genetic markers might be able to genetically differentiate between cultivars (see Risjani and Abidin 2020; Thien et al. 2020). High throughput sequencing and single nucleotide polymorphisms (SNPs) have been helpful in exploring the neutral and functional genetic diversity between terrestrial crops thereby allowing detection of misclassified cultivars, examining reduction of genetic diversity and accumulation of deleterious alleles during selection steps (Diaz-Garcia et al. 2020; O'Connor et al. 2019). These techniques might be usefully applied for eucheumatoid cultivars in future researches.

Vegetative propagation and transfer of clones (ramets) between farms and areas impact genetic diversity in crops due to recurrent bottlenecks. The narrowing of the genetic basis begins with selection of a few strains of interest from wild environments and is intensified during the development of elite cultivars through ongoing artificial selection. This mode of propagation dramatically affects crop genetic diversity (McKey et al. 2010; Meyer et al. 2012; Smýkal et al. 2018). In potatoes and yam for example, farming based on asexual reproduction has led to a severe reduction of genetic diversity and an accumulation of deleterious alleles (Pandey et al. 2021; Ramu et al. 2017). Although the history of domestication is more recent in seaweeds, typical impacts of extensive use of vegetative propagation in farms, include the very low levels of clonal variation, life cycle disruption, and reduction in reproductive effort as has been detected in the red alga *G. chilensis* (Guillemin et al. 2008; Usandizaga et al. 2021). The problem could be especially acute in eucheumatoid farms where cultivation from vegetative thalli has led to the wide use of mitochondrially similar haplotypes around the world (Zuccarello et al. 2006). These farmed haplotypes have spread to adjacent areas both in the Philippines and in regions where these cultivars have been introduced (Dumilag et al. 2016b; Halling et al. 2013; Tano et al. 2015).

High genetic and phenotypic diversity is expected in naïve areas of crop origin (e.g. Hardigan et al. 2017). In the Philippines, a number of natural populations of eucheumatoids are located near the farms and dispersal probably occurs between farmed plants and wild populations of both sporophytes and gametophytes (R. V. Dumilag, personal observation). Such conditions could help to delay the genetic diversity loss during domestication allowing introduction of new alleles at each generation even in highly asexually cultivated crops (Elias et al. 2001). Exchange of cultivars among Filipino farmers could also help to maintain large population sizes, increase genetic varianition in multiple populations, but only through somatic mutations. Introgression of new alleles in crops due to natural crosses with individuals from nearby natural populations or distinct cultivars introduced from other regions could generate new genotypic combinations and potentially superior cultivars without the burden of performing costly breeding effort (Labeyrie et al. 2016; Pautasso et al. 2013). Unfortunately sexual reproduction and selection of new sporelings are uncommon practice among seaweed farmers. The continuous discovery of new eucheumatoid haplotypes demonstrates that high genetic diversity is available in both farms and natural populations and also remain to be uncovered in the Philippines (Dumilag et al. 2016a, 2018; Roleda et al. 2021a). It is therefore imperative to further explore this untapped diversity and to create seedbanks from sites without cultivation activity. These strategies could mitigate the decline of genetic diversity and can provide access to genetic variants better adapted to unprecedented challenges of the current seaweed farming systems. Other conservation strategies that can be applied for eucheumatoids include *ex situ* conservation such as germplasm banking through culture (De La Fuente et al. 2019; Wade et al. 2020; Watanabe 2005) and cryopreservation (Yang et al. 2021), as well as *in situ* conservation (Wambugu and Henry 2022). The high number of cultivars in the Philippines makes the region an excellent area for the discovery of new cultivars that can be preserved and their economic potential explored in future crop selection and breeding programs.

Conclusion and future directions

The extent to which the role of cultivar diversity can potentially contribute to advancing phyconomy is still largely under researched. Given the need to maintain cultivar diversity, as a means of promoting resilience of seaweed crops to disease and pests, and the increasing potential use of carrageenan and other key biomolecules in medical (Morokutti-Kurz et al. 2021; Pereira and Critchley 2020) and in some extent, to bioplastics industry (Schmidtchen et al. 2022), selection for appropriate cultivars needs to be investigated. Future studies on cultivar diversity would benefit from greater integration of ethnophycology (the study of the relationship between seaweeds and people; see Brodie 2010) on farming practices, and explicit consideration of how farmers perceive cultivar-level variability. Integration of farmer knowledge and their acceptance of research outcomes are essential to produce and utilize new cultivars.

Funding

This study was primarily supported by the research fund from the United Kingdom Research and Innovation–Global Challenges Research Fund (UKRI- GCRF) 'GlobalSeaweedSTAR' Programme GSS/RF/015 (BB/P027806/1) awarded to RVD and MYR. RVD, FDG and HARQ were respectively supported by the Department of Science and Technology (DOST), Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD) projects: Molecular characterization, selection and production of high quality eucheumatoid cultivars in the Bangsamoro Autonomous Region in Muslim Mindanao, Field Testing of Laboratory-reared Seaweed Cultivars from PSU-MSL Culture Facilities in MIMAROPA Region and Seaweed Area GIS-based Mapping: Production Support System for Sustainable Seaweeds Farming in the Philippines. MYR was supported by the DOST-Balik Scientist Program (BSP) fellowship, the UP System Balik PhD Program (OVPAA-BPhD-2019-06), and the UPMSI inhouse research grant.

ORCID

Richard V. Dumilag http://orcid.org/0000-0002-7590-0009
Bea A. Crisostomo http://orcid.org/0000-0002-0928-5837
Zae-Zae A. Aguinaldo http://orcid.org/0000-0003-3668-374X
Lourie Ann R. Hinaloc http://orcid.org/0000-0002-7736-9485
Lawrence M. Liao http://orcid.org/0000-0001-5484-6560
Hilly Ann Roa-Quiaoit http://orcid.org/0000-0001-5615-0786
Floredel Dangan-Galon http://orcid.org/0000-0002-3494-8380
Giuseppe C. Zuccarello http://orcid.org/0000-0003-0028-7227
Marie-Laure Guillemin http://orcid.org/0000-0001-5703-7662
Juliet Brodie http://orcid.org/0000-0001-7622-2564
Elizabeth J. Cottier-Cook http://orcid.org/0000-0002-1466-6802
Michael Y. Roleda http://orcid.org/0000-0003-0568-9081

References

Adharini RI, Suyono EA, SuadiJayanti AD, Setyawan AR. 2019. A comparison of nutritional values of *Kappaphycus alvarezii*, *Kappaphycus striatum*, and *Kappaphycus spinosum* from the farming sites in Gorontalo Province, Sulawesi, Indonesia. J Appl Phycol. 31(1):725–730. doi:10.1007/s10811-018-1540-0

Ali MM, Sani MZB, Hi KK, Yasir SM, Critchley AT, Hurtado AQ. 2018. The comparative efficiency of a brown algal-derived biostimulant extract (AMPEP), with and without supplemented PGRs: the induction of direct, axis shoots as applied to the propagation of vegetative seedlings for the successful mass cultivation of three commercial strains of *Kappaphycus* in Sabah, Malaysia. J Appl Phycol. 30(3):1913–1919. doi:10.1007/s10811-017-1366-1

Andriesse E, Lee Z. 2017. Viable insertion in agribusiness value chains? Seaweed farming after Typhoon Yolanda (Haiyan) in Iloilo Province, the Philippines. Singap J Trop Geogr. 38(1):25–40. doi:10.1111/sjtg.12178

Asfaw BT, Worojie TB, Mengesha WA. 2021. Assessing morphological diversity in Ethiopian yams (*Dioscorea* spp.) and its correspondence with folk taxonomy. Syst Biodivers. 19(5):471–487. doi:10.1080/14772000.2021.1890269

Azanza-Corrales R, Mamauag SS, Alfiler E, Orolfo MJ. 1992. Reproduction in *Eucheuma denticulatum* (Burman) Collins and Hervey and *Kappaphycus alvarezii* (Doty) Doty farmed in Danajon Reef, Philippines. Aquaculture 103(1):29–34. doi:10.1016/0044-8486(92)90275-P

Bhattacharyya S, Feferman L, Tobacman JK. 2019. Distinct effects of carrageenan and high-fat consumption on the mechanisms of insulin resistance in nonobese and obese models of type 2 diabetes. J Diabetes Res. 2019:9582714. doi:10.1155/2019/9582714

Bindu MS, Levine IA. 2011. The commercial red seaweed *Kappaphycus alvarezii*—an overview on farming and environment. J Appl Phycol. 23(4):789–796. doi:10.1007/s10811-010-9570-2

Bixler HJ, Porse H. 2011. A decade of change in the seaweed hydrocolloids industry. J Appl Phycol. 23(3):321–335. doi:10.1007/s10811-010-9529-3

Blake FR. 1917. Reduplication in Tagalog. Am J Philol. 38(4):425–431. doi:10.2307/288967

Blanchetti-Revelli L. 1995. Canadian misfortunes and Filipino fortunes: the invention of seaweed mariculture and the geographical reorganization of seaweed production. In: McMichael P, editor. Food and agrarian orders in the world economy. Westport (CT): Praeger Publishers. p. 97–112.

Bolton JJ. 2020. The problem of naming commercial seaweeds. J Appl Phycol. 32(2):751–758. doi:10.1007/s10811-019-01928-0

Borlongan IAG, Tibubos KR, Yunque DAT, Hurtado AQ, Critchley AT. 2011. Impact of AMPEP on the growth and occurrence of epiphytic *Neosiphonia* infestation on two varieties of commercially cultivated *Kappaphycus alvarezii* grown at different depths in the Philippines. J Appl Phycol. 23(3):615–621. doi:10.1007/s10811-010-9649-9

Bouanati T, Colson E, Moins S, Cabrera J-C, Eeckhaut I, Raquez J-M, Gerbaux P. 2020. Microwave-assisted depolymerization of carrageenans from *Kappaphycus alvarezii* and *Eucheuma spinosum*: Controlled and green production of oligosaccharides from the algae biomass. Algal Res. 51:102054. doi:10.1016/j.algal.2020.102054

Brakel J, Sibonga RC, Dumilag RV, Montalescot V, Campbell I, Cottier-Cook EJ, Ward G, Le Masson V, Liu T, Msuya FE, et al. 2021. Exploring, harnessing and conserving marine genetic resources towards a sustainable seaweed aquaculture. Plants People Planet. 3(4):337–349. doi:10.1002/ppp3.10190

Brickell CD, Alexander C, Cubey JjDavid JcHoffman MHM, Leslie AcMalécot V, Jin X. 2016. International code of nomenclature for cultivated plants (ICNCP or cultivated plant code) Scripta Hort 18. 9th ed. The Netherlands: Drukkerij Station Drukwerk.

Brodie J. 2010. Global Seaweed Network: a global seaweed strategy. [accessed 2021 Sep 28]. https://www.nhm.ac.uk/our-science/our-work/biodiversity/global-seaweed-network.html.

Chabi MC, Dassou AG, Dossou-Aminon I, Ogouchoro D, Aman BO, Dansi A. 2018. Banana and plantain production systems in Benin: ethnobotanical investigation, varietal diversity, pests, and implications for better production. J Ethnobiol Ethnomedicine 14(1):78. doi: 10.1186/s13002-018-0280-1.

Charrier B, Rolland E, Gupta V, Reddy RK. 2015. Production of genetically and developmentally modified seaweeds: exploiting the potential of artificial selection techniques. Front Plant Sci. 6(127):127. doi: 10.3389/fpls.2015.00127.

Chopin T, Tacon AGJ. 2021. hahahahahah of seaweeds and extractive species in global aquaculture production. Rev Fish Sci Aquac. 29(2):139–148. doi:10.1080/23308249.2020.1810626

Cottier-Cook EJ, Nagabhatla N, Badis Y, Campbell M, Chopin T, Dai W, Fang J, He P, Hewitt C, Kim GH. 2016. Safeguarding the future of the global seaweed aquaculture industry. Hamilton (ON/Canada): United Nations University and Scottish Association for Marine Science. Policy brief. [accessed 2021 Aug 8]. https://www.sams.ac.uk/t4-media/sams/pdf/globalseaweed-policy-brief.pdf.

Critchley AT, Ohno M. 1998. Seaweed resources of the world. Yokosuka: Japan International Cooperation Agency.

Cuaton GP. 2019. A post-disaster gendered value chain analysis on seaweed farming after Super Typhoon Haiyan in the Philippines. JEC. 13(4):508–534. doi:10.1108/JEC-11-2018-0091

David SS, Levi C, Fahoum L, Ungar Y, Meyron-Holtz EG, Shpigelman A, Lesmes U. 2018. Revisiting the carrageenan controversy: Do we really understand the digestive fate and safety of carrageenan in our foods? Food Funct. 9(3):1344–1352. doi:10.1039/c7fo01721a

de Haan S, Bonierbale M, Ghislain M, Núñez J, Trujillo G. 2007. Indigenous biosystematics of Andean potatoes: Folk taxonomy, descriptors and nomenclature. Acta Hortic. 745(745):89–134. doi:10.17660/ActaHortic.2007.745.4

De La Fuente G, Chiantore M, Asnaghi V, Kaleb S, Falace A. 2019. First *ex situ* outplanting of the habitat-forming seaweed *Cystoseira amentacea* var. *stricta* from a restoration perspective. PeerJ 7:e7290. doi:10.7717/peerj.7290

Derby N, Lal M, Aravantinou M, Kizima L, Barnable P, Rodriguez A, Lai M, Wesenberg A, Ugaonkar S, Levendosky K, et al. 2018. Griffithsin carrageenan fast dissolving inserts prevent SHIV HSV-2 and HPV infections in vivo. Nat Commun. 9(1):3881. doi:10.1038/s41467-018-06349-0

Diaz-Garcia L, Covarrubias-Pazaran G, Johnson-Cicalese J, Vorsa N, Zalapa J. 2020. Genotyping-by-sequencing identifies historical breeding stages of the recently domesticated American cranberry. Front Plant Sci. 11:607770. doi:10.3389/fpls.2020.607770

Dong Y, Wei Z, Xue C. 2021. Recent advances in carrageenan-based delivery systems for bioactive ingredients: A review. Trends Food Sci Technol. 112:348–361. doi:10.1016/j.tifs.2021.04.012

Doty MS. 1973. Farming the red seaweed. Eucheuma, for carrageenans. Micronesica. 9:59–73.

Doty MS. 1985. Eucheuma alvarezii, sp. nov. (Gigartinales, Rhodophyta) from Malaysia. In: Abbott IA, Norris JN, editors. Taxonomy of economic seaweeds: with reference to some Pacific and Caribbean species. Vol. 1. La Jolla (CA): California Sea Grant College Program. p. 37–45.

Doty MS. 1988. Prodromus ad systematica Eucheumatoideorum: a tribe of commercial seaweeds related to Eucheuma (Solieriaceae, Gigartinales) In: Abbott IA, editor. Taxonomy of economic seaweeds with reference to some Pacific and Caribbean species. Vol. 2. La Jolla (CA): University of California. p. 159–207.

Doty MS. 1995. Betaphycus philippinensis gen. et sp. nov. and related species (Solieriaceae, Gigartinales). In: Abbott IA, editor. Taxonomy of economic seaweeds with reference to some Pacific and Caribbean species. Vol. 5. La Jolla (CA): University of California. p. 237–245.

Doty MS, Alvarez VB. 1973. Seaweed farms. A New Approach for U. S. industry. In: Proceedings of 9th Annual Conference of the Marine Technology Society; 1973 Sept 10–12; Washington DC. p. 701–708.

Doty MS, Alvarez VB. 1975. Status, problems, advances, and economics of *Eucheuma* farms. Mar Technol Soc J. 9:30–35.

Duarte CM, Wu J, Xiao X, Bruhn A, Krause-Jensen D. 2017. Can seaweed farming play a role in climate change mitigation and adaptation? Front Mar Sci. 4:100. doi: 10.3389/fmars.2017.00100.

Dumilag RV. 2019. Edible seaweeds sold in the local public markets in Tawi-Tawi, Philippines. Philipp J Sci. 148(4):803–811.

Dumilag RV, Gallardo WGM, Garcia CPC, You Y, Chaves AKG, Agahan L. 2018. Phenotypic and mtDNA variation in Philippine *Kappaphycus cottonii* (Gigartinales, Rhodophyta). Mitochondrial DNA A DNA Mapp Seq Anal. 29(6):951–963. doi:10.1080/24701394.2017.1398745

Dumilag RV, Lin SM, Zuccarello GC, Kraft GT. 2020. The identity of *Eucheuma perplexum* (Solieriaceae, Gigartinales) and its distinction from *Eucheuma serra* as exemplified by a proposed new epitype. Phycologia 59(6):497–505. doi:10.1080/00318884.2020.1797375

Dumilag RV, Lluisma AO. 2014. Resolving the phylogenetic affinities of *Kappaphycus inermis* within the genus *Kappaphycus* (Gigartinales, Solieriaceae) using mitochondrial and plastid markers. Phytotaxa 162(4):223–231. doi:10.11646/phytotaxa.162.4.5

Dumilag RV, Orosco FL, Lluisma AO. 2016a. Genetic diversity of *Kappaphycus* species (Gigartinales, Rhodophyta) in the Philippines. Syst Biodivers. 14(5):441–451. doi:10.1080/14772000.2016.1157643

Dumilag RV, Salvador RC, Halling C. 2016b. Genotype introduction affects population composition of native Philippine *Kappaphycus* (Gigartinales, Rhodophyta). Conservation Genet Resour. 8(4):439–441. doi:10.1007/s12686-016-0591-2

Elias M, Penet L, Vindry P, McKey D, Panaud O, Robert T. 2001. Unmanaged sexual reproduction and the dynamics of genetic diversity of a vegetatively propagated crop plant, cassava (*Manihot esculenta* Crantz), in a traditional farming system. Mol Ecol. 10(8):1895–1907. doi:10.1046/j.0962-1083.2001.01331.x

Faisan JP, Luhan MRJ, Sibonga RC, Mateo JP, Ferriols VMEN, Brakel J, Ward GM, Ross S, Bass D, Stentiford GD, et al. 2021. Preliminary survey of pests and diseases of eucheumatoid seaweed farms in the Philippines. J Appl Phycol. 33(4):2391–2405. doi:10.1007/s10811-021-02481-5

FAO. 2020. The state of world fisheries and aquaculture: sustainability in action. Rome (Italy): FAO. p. 1–206. doi: 10.4060/ca9229en.

Fredericq S, Freshwater DW, Hommersand MH. 1999. Observations on the phylogenetic systematics and biogeography of the Solieriaceae (Gigartinales, Rhodophyta) inferred from *rbc*L sequences and morphological evidence. Hydrobiologia. 398/399:25–38. doi:10.1023/A:1017077831840

Frediansyah A. 2021. The antiviral activity of iota-, kappa-, and lambda-carrageenan against COVID-19: A critical review. Clin Epidemiology Glob Health 12:100826. doi: 10.1016/j.cegh.2021.100826.

Froehlich HE, Afflerbach JC, Frazier M, Halpern BS. 2019. Blue growth potential to mitigate climate change through seaweed offsetting. Curr Biol. 29(18):3087–3093.e3. doi:10.1016/j.cub.2019.07.041

Fry HT. 1970. Alexander Dalrymple (1737–1808) and the expansion of British trade. London (United Kingdom): Frank Cass & Co.

Ganzon-Fortes ET, Trono GC, Villanueva RD, Romero JB, Montaño MNE. 2012. Endong', a rare variety of the farmed carrageenophyte *Eucheuma denticulatum* (Burman) Collins & Hervey from the Philippines. J Appl Phycol. 24(5):1107–1111. doi:10.1007/s10811-011-9740-x

Glenn EP, Doty MS. 1992. Water motion affects the growth rates of *Kappaphycus alvarezii* and related red seaweeds. Aquaculture 108(3–4):233–246. doi:10.1016/0044-8486(92)90109-X

Guillemin ML, Faugeron S, Destombe C, Viard F, Correa JA, Valero M. 2008. Genetic variation in wild and cultivated populations of the haploid-diploid red alga Gracilaria chilensis: how farming practices favor asexual reproduction and heterozygosity. Evolution. 62(6):1500–1519. doi:10.1111/j.1558-5646.2008.00373.x

Guo Z, Wei Y, Zhang Y, Xu Y, Zheng L, Zhu B, Yao Z. 2022. Carrageenan oligosaccharides: A comprehensive review of preparation, isolation, purification, structure, biological activities and applications. Algal Res. 61(102593):102593. doi:10.1016/j.algal.2021.102593

Gurav R, Bhatia SK, Choi T-R, Choi Y-K, Kim HJ, Song H-S, Lee SM, Lee Park S, Lee HS, Koh J, et al. 2021. Application of macroalgal biomass derived biochar and bioelectrochemical system with *Shewanella* for the adsorptive removal and biodegradation of toxic azo dye. Chemosphere 264(Pt 2):128539. doi:10.1016/j.chemosphere.2020.128539

Halling C, Wikström SA, Lilliesköld-Sjöö G, Mörk E, Lundsør E, Zuccarello GC. 2013. Introduction of Asian strains and low genetic variation in farmed seaweeds: indications for new management practices. J Appl Phycol. 25(1):89–95. doi:10.1007/s10811-012-9842-0

Hardigan MA, Laimbeer FPE, Newton L, Crisovan E, Hamilton JP, Vaillancourt B, Wiegert-Rininger K, Wood JC, Douches DS, Farré EM, et al. 2017. Genome diversity of tuber-bearing *Solanum* uncovers complex evolutionary history and targets of domestication in the cultivated potato. Proc Natl Acad Sci U S A. 114(46):E9999–E10008. doi:10.1073/pnas.1714380114

Hayashi L, de Paula EJ, Chow F. 2007. Growth rate and carrageenan analyses in four strains of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) farmed in the subtropical waters of São Paulo State, Brazil. J Appl Phycol. 19(5):393–399. doi:10.1007/s10811-006-9135-6

Heery EC, Lian KY, Loke LHL, Tan HTW, Todd PA. 2020. Evaluating seaweed farming as an eco-engineering strategy for 'blue' shoreline infrastructure. Ecol Eng. 152:105857. doi:10.1016/j.ecoleng.2020.105857

Hinaloc LAR, Roleda MY. 2021. Phenotypic diversity, growth and sexual differentiation in the progeny of wild *Kappaphycus alvarezii* (Gigartinales, Florideophyceae). Phycologia 60(6):547–557. doi:10.1080/00318884.2021.1946307

Hopkins NA. 2006. The place of maize in indigenous Mesoamerican folk taxonomies. In: Staller JE, Tykot RH, Benz BF, editors. Histories of maize: Multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize. Burlington (MA): Elsevier/Academic Press. p. 612–622.

Hu ZM, Shan TF, Zhang J, Zhang QS, Critchley AT, Choi HG, Yotsukura N, Liu FL, Duan DL. 2021. Kelp aquaculture in China: a retrospective and future prospects. Rev Aquacult. 13(3):1324–1351. doi:10.1111/raq.12524

Hurtado AQ. 2013. Different colour morphotypes of Kappaphycus alvarezii and Kappaphycus striatum used in commercial farming. In: Phang SM, Lim PE, editors. Taxonomy of Southeast Asian seaweeds II. Kuala Lumpur, Malaysia: University of Malaya Press. p. 83–92.

Hurtado AQ, Biter AB. 2007. Plantlet regeneration of *Kappaphycus alvarezii* var. *adik-adik* by tissue culture. J Appl Phycol. 19(6):783–786. doi:10.1007/s10811-007-9269-1

Hurtado AQ, Lim PeTan J. Phang SmNeish Ic, Critchley At. 2016. Biodiversity and biogeography of commercial tropical carrageenophytes in the Southeast Asian region. In: Pereira L, editor. Carrageenans: Sources and extraction methods, molecular structure, bioactive properties and health effects. (NY): Nova Science Publishers. p. 51–74.

Hurtado AQ, Neish IC, Critchley AT. 2019. Phyconomy: the extensive cultivation of seaweeds, their sustainability and economic value, with particular reference to important lessons to be learned and transferred from the practice of eucheumatoid farming. Phycologia 58(5):472–483. doi:10.1080/00318884.2019.1625632

Hurtado AQ, Yunque DA, Tibubos K, Critchley AT. 2009. Use of Acadian marine plant extract powder from *Ascophyllum nodosum* in tissue culture of *Kappaphycus* varieties. J Appl Phycol. 21(6):633–639. doi:10.1007/s10811-008-9395-4

Hussin H, Khoso A. 2021. Migrant workers in the seaweed sector in Sabah, Malaysia. SAGE Open. 11(3): 215824402110475–215824402110412. doi:10.1177/21582440211047586

Hwang EK, Yotsukura N, Pang SJ, Su L, Shan TF. 2019. Seaweed breeding programs and progress in eastern Asian countries. Phycologia 58(5):484–495. doi:10.1080/00318884.2019.1639436.

Jana S, Manna S, Sen KK, Jana S, 2022. Marine biopolymers for oral delivery of drug. In: Jana S, Jana S. editors. Marine biomaterials. Singapore: Springer. p. 1–13.

Jang Y, Shin H, Lee MK, Kwon OS, Shin JS, Kim Y, Kim CW, Lee H, Kim M. 2021. Antiviral activity of lambda-carrageenan against influenza viruses and severe acute respiratory syndrome coronavirus 2. Sci Rep. 11(1):821. doi:10.1038/s41598-020-80896-9

Jayakody MM, Vanniarachchy MPG, Wijesekara I. 2022. Seaweed derived alginate, agar, and carrageenan based edible coatings and films for the food industry: a review. J Food Meas Charact. 16(2):1195–1227. doi:10.1007/s11694-021-01277-y

Jueterbock A, Minne AJP, Cock JM, Coleman MA, Wernberg T, Scheschonk L, Rautenberger R, Zhang J, Hu ZM. 2021. Priming of marine macrophytes for enhanced restoration success and food security in future oceans. Front Marine Sci 8:658485. doi: 10.3389/fmars.2021.658485.

Kelly ELA, Cannon AL, Smith JE. 2020. Environmental impacts and implications of tropical carrageenophyte seaweed farming. Conserv Biol. 34(2):326–337. doi:10.1111/cobi.13462

Kluyver TA, Jones G, Pujol B, Bennett C, Mockford EJ, Charles M, Rees M, Osborne CP. 2017. Unconscious selection drove seed enlargement in vegetable crops. Evol Lett. 1(2):64–72. doi:10.1002/evl3.6

Kraft GT. 1997. In memoriam, Maxwell Stanford Doty (1916-1996). Phycologia 36(1):82–90. doi:10.2216/i0031-8884-36-1-82.1

Labeyrie V, Thomas M, Muthamia ZK, Leclerc C. 2016. Seed exchange networks, ethnicity, and sorghum diversity. Proc Natl Acad Sci U S A. 113(1):98–103. doi:10.1073/pnas.1513238112

Largo DB, Chung IkPhang SmGerung Gs, Sondak CFA. 2017. Impacts of climate change on Eucheuma-Kappaphycus farming. In: Hurtado A, Critchley A, Neish I, editors. Tropical seaweed farming trends, problems and opportunities. Developments in applied phycology, vol 9. Cham: Springer. p. 121–129. doi: 10.1007/978-3-319-63498-2_7.

Larson S, Stoeckl N, Fachry ME, Dalvi Mustafa M, Lapong I, Purnomo AH, Rimmer MA, Paul NA. 2021. Women's well-being and household benefits from seaweed farming in Indonesia. Aquaculture 530:735711. doi:10.1016/j.aquaculture.2020.735711

Li Y, Liu N, Wang X, Tang X, Zhang L, Meinita MDN, Wang G, Yin H, Jin Y, Wang H, et al. 2018. Comparative genomics and systematics of *Betaphycus*, *Eucheuma*, and *Kappaphycus* (Solieriaceae: Rhodophyta) based on mitochondrial genome. J Appl Phycol. 30(6):3435–3443. doi:10.1007/s10811-018-1450-1

Liao LM. 1996. Validation of names transferred to *Kappaphycus* Doty from. Eucheuma J. Agardh (Rhodophyta: Solieriaceae). Philipp J Sci. 125(2):158–160.

Liao LM. 2013. An early 18th century account of marine algae from the Philippines. Philipp J Sci. 142(Spec Iss):113–117.

Lim P-E, Yang L-E, Tan J, Maggs CA, Brodie J. 2017. Advancing the taxonomy of economically important red seaweeds (Rhodophyta). Eur J Phycol. 52(4):438–451. doi:10.1080/09670262.2017.1365174

Liu F, Hou P, Zhang H, Tang Q, Xue C, Li RW. 2021. Food-grade carrageenans and their implications in health and disease. Compr Rev Food Sci Food Saf. 20(4):3918–3936. doi:10.1111/1541-4337.12790

Loko YLE, Ewedje E-E, Orobiyi A, Djedatin G, Toffa J, Gbemavo CDSJ, Tchakpa C, Gavoedo D, Sedah P, Sabot F. 2021. On-farm management of rice diversity, varietal preference criteria, and farmers' perceptions of the African (*Oryza glaberrima* Steud.) versus Asian rice (*Oryza sativa* L.) in the Republic of Benin (West Africa): Implications for breeding and conservation. Econ Bot. 75(1):1–29. doi:10.1007/s12231-021-09515-6

Mansa RF, Chen WC, Yeo S, Farm Y, Bakar HA, Sipaut CS, 2013. Fermentation study on macroalgae Eucheuma cottonii for bioethanol production via varying acid hydrolysis. In: Pogaku R, Sarbatly RH, editors. Advances in biofuels. Boston (MA): Springer. p. 219–240.

Marchi F, Plastino EM. 2020. Codominant inheritance of polymorphic color mutant and characterization of a bisexual mutant of *Gracilaria caudata* (Gracilariales, Rhodophyta). J Appl Phycol. 32(6):4385–4398. doi:10.1007/s10811-020-02199-w

Matanjun P, Mohamed S, Mustapha NM, Muhammad K. 2009. Nutrient content of tropical edible seaweeds, *Eucheuma cottonii*, *Caulerpa lentillifera* and *Sargassum* *polycystum*. J Appl Phycol. 21(1):75–80. doi:10.1007/s10811-008-9326-4

Mateo JP, Campbell I, Cottier-Cook EJ, Luhan MRJ, Ferriols VMEN, Hurtado AQ. 2021. Understanding biosecurity: knowledge, attitudes and practices of seaweed farmers in the Philippines. J Appl Phycol. 33(2):997–1010. doi:10.1007/s10811-020-02352-5

Mattes V. 2014. Types of reduplication: A case study of Bikol. Berlin (Germany): De Gruyter Mouton.

McKey D, Elias M, Pujol B, Duputié A. 2010. The evolutionary ecology of clonally propagated domesticated plants. New Phytol. 186(2):318–332. doi:10.1111/j.1469-8137.2010.03210.x

McKim JM, Willoughby JA, Blakemore WR, Weiner ML. 2019. Clarifying the confusion between poligeenan, degraded carrageenan, and carrageenan: A review of the chemistry, nomenclature, and in vivo toxicology by the oral route. Crit Rev Food Sci Nutr. 59(19):3054–3073. doi:10.1080/10408398.2018.1481822

Mendoza WG, Montaño NE, Ganzon-Fortes ET, Villanueva R. 2002. Chemical and gelling profile of ice-ice infected carrageenan from *Kappaphycus* striatum (Schmitz) Doty "sacol" strain (Solieriaceae, Gigartinales, Rhodophyta). J Appl Phycol. 14(5):409–418. doi:10.1023/A:1022178119120

Meyer RS, DuVal AE, Jensen HR. 2012. Patterns and processes in crop domestication: an historical review and quantitative analysis of 203 global food crops. New Phytol. 196(1):29–48. doi:10.1111/j.1469-8137.2012.04253.x

Morokutti-Kurz M, Fröba M, Graf P, Große M, Grassauer A, Auth J, Schubert U, Prieschl-Grassauer E. 2021. Iota-carrageenan neutralizes SARS-CoV-2 and inhibits viral replication in vitro. PLoS ONE 16(2):e0237480. doi:10.1371/journal.pone.0237480

Msuya FE, Hurtado AQ. 2017. The role of women in seaweed aquaculture in the Western Indian Ocean and South-East Asia. Eur J Phycol. 52(4):482–494. doi:10.1080/09670262.2017.1357084

Nantale G, Kakudidi EK, Karamura DA, Soka G. 2008. Scientific basis for banana cultivar proportions on-farm in East Africa. Afr Crop Sci J. 16(1):41–49. doi: 10.4314/acsj.v16i1.54338.

Narvarte BCV, Genovia TGT, Hinaloc LAR, Roleda MY. 2022. Growth, nitrate uptake kinetics, and biofiltration potential of eucheumatoids with different thallus morphologies. J Phycol. 58(1):12–21. doi:10.1111/jpy.13229

Naylor RL, Hardy RW, Buschmann AH, Bush SR, Cao L, Klinger DH, Little DC, Lubchenco J, Shumway SE, Troell M. 2021. A 20-year retrospective review of global aquaculture. Nature 591(7851):551–563. doi:10.1038/s41586-021-03308-6

Neish IC, Sepulveda M, Hurtado Aq, Critchley At. 2017. Reflections on the commercial development of eucheumatoid seaweed farming. In: Hurtado AQ, Critchley AT, Neish IC, editors. Tropical seaweed farming trends, problems and opportunities: focus on Kappaphycus and Eucheuma. Cham (Switzerland): Springer. p. 1–27. doi: 10.1007/978-3-319-63498-2_1.

Nimmo AH. 1986. Recent population movements in the Sulu Archipelago: Implications to Sama culture history. Archipel 32:25–38. doi: 10.3406/arch.1986.2307.

Niwa K, Abe T. 2012. Chimeras with mosaic pattern in archeospore germlings of *Pyropia yezoensis* Ueda (Bangiales, RHODOPHYTA)(1). J Phycol. 48(3):706–709. doi:10.1111/j.1529-8817.2012.01143.x

Nor AM, Gray TS, Caldwell GS, Stead SM. 2017. Is a co-operative approach to seaweed farming effectual? An analysis of the seaweed cluster project (SCP), Malaysia. J Appl Phycol. 29(5):2323–2337. doi:10.1007/s10811-016-1025-y

Norris JN. 2014. Marine algae of the northern Gulf of California II: Rhodophyta. Smithson Contrib Bot. 96(96):1–555. doi:10.5479/si.19382812.96

Núñez-Resendiz ML, Dreckmann KM, Sentíes A, Wynne MJ, León-Tejera HP. 2019. *Eucheumatopsis isiformis* gen. & comb. nov. (Solieriaceae, Rhodophyta) from the Yucatan Peninsula, to accommodate *Eucheuma isiforme*. Phycologia 58(1):51–62. doi:10.1080/00318884.2018.1517536

O'Connor K, Kilian A, Hayes B, Hardner C, Nock C, Baten A, Alam M, Topp B. 2019. Population structure, genetic diversity and linkage disequilibrium in a macadamia breeding population using SNP and silicoDArT markers. Tree Genet Genomes 15(24):1–16. doi: 10.1007/s11295-019-1331-z.

Pandey J, Scheuring DC, Koym JW, Coombs J, Novy RG, Thompson AL, Holm DG, Douches DS, Miller JC, Vales MI. 2021. Genetic diversity and population structure of advanced clones selected over forty years by a potato breeding program in the USA. Sci Rep. 11(1):1–18. doi:10.1038/s41598-021-87284-x

Parenrengi A, Dworjanyn S, Syah R, Pongmasak PR, Fahrur M. 2020. Strain selection for growth enhancement of wild and cultivated eucheumatoid seaweed species in Indonesia. JSM 49(10):2453–2464. doi:10.17576/jsm-2020-4910-11

Parker HS. 1974. The culture of the red algal genus *Eucheuma* in the Philippines. Aquac 3(4):425–439. doi:10.1016/0044-8486(74)90009-X

Pautasso M, Aistara G, Barnaud A, Caillon S, Clouvel P, Coomes OT, Delêtre M, Demeulenaere E, De Santis P, Döring T, et al. 2013. Seed exchange networks for agrobiodiversity conservation. A review. Agron Sustain Dev. 33(1):151–175. doi:10.1007/s13593-012-0089-6

Pereira L, Critchley AT. 2020. The COVID 19 novel coronavirus pandemic 2020: seaweeds to the rescue? Why does substantial, supporting research about the antiviral properties of seaweed polysaccharides seem to go unrecognized by the pharmaceutical community in these desperate times? J Appl Phycol. 32(3):1875–1877. doi:10.1007/s10811-020-02143-y

Periyasamy C, Anantharaman P, Balasubramanian T. 2014. Social upliftment of coastal fisher women through seaweed (*Kappaphycus alvarezii* (Doty) Doty) farming in Tamil Nadu, India. J Appl Phycol. 26(2):775–781. doi:10.1007/s10811-013-0228-8

Phang S-M, Yeong H-Y, Lim P-E, Nor ARM, Gan KT. 2010. Commercial varieties of *Kappaphycus* and *Eucheuma* in Malaysia. MJS 29(3):214–224. doi:10.22452/mjs.vol29no3.4

Plastino EM, Guimarães M, Matioli SR, Oliveira EC. 1999. Codominant inheritance of polymorphic color variants of *Gracilaria domingensis* (Gracilariales, Rhodophyta). Genet Mol Biol. 22(1):105–108. doi:10.1590/S1415-47571999000100020

Purbosari N, Warsiki E, Syamsu K, Santoso J, Effendi I. 2021. Evaluation of the application of seaweed (*Eucheuma* *cottonii*) extract as fish anesthetic agent. Aquacult Int. 29(4):1545–1560. doi:10.1007/s10499-021-00693-7

Quiaoit HAR, Uy WH, Bacaltos DGG, Chio PBR. 2016. Seaweed area GIS-based mapping. Production support system for sustainable seaweed farming in the Philippines 2016 report. Cagayan de Oro (Philippines): Xavier University Press.

Ramu P, Esuma W, Kawuki R, Rabbi IY, Egesi C, Bredeson JV, Bart RS, Verma J, Buckler ES, Lu F. 2017. Cassava haplotype map highlights fixation of deleterious mutations during clonal propagation. Nat Genet. 49(6):959–963. doi:10.1038/ng.3845

Risjani Y, Abidin G. 2020. Genetic diversity and similarity between green and brown morphotypes of *Kappaphycus alvarezii* using RAPD. J Appl Phycol. 32(4):2253–2260. doi:10.1007/s10811-020-02223-z

Roleda MY, Aguinaldo Z-ZA, Crisostomo BA, Hinaloc LAR, Projimo VZ, Dumilag RV, Lluisma AO. 2021a. Discovery of novel haplotypes from wild populations of *Kappaphycus* (Gigartinales, Rhodophyta) in the Philippines. Algae 36(1):1–12. doi:10.4490/algae.2021.36.2.18

Roleda MY, Heesch S. 2021. Chemical profiling of Ulva species for food applications: What is in a name? Food Chem. 361:130084. doi:10.1016/j.foodchem.2021.130084

Roleda MY, Hurd CL. 2019. Seaweed nutrient physiology: Application of concepts to aquaculture and bioremediation. Phycologia 58(5):552–562. doi:10.1080/00318884.2019.1622920

Roleda MY, Lage S, Aluwini DF, Rebours C, Brurberg MB, Nitschke U, Gentili FG. 2021b. Chemical profiling of the Arctic sea lettuce *Ulva lactuca* (Chlorophyta) mass-cultivated on land under controlled conditions for food applications. Food Chem. 341(Pt 1):127999. doi:10.1016/j.foodchem.2020.127999

Roleda MY, Lage S, Aluwini DF, Rebours C, Brurberg MB, Nitschke U, Gentili FG. 2021c. Corrigendum to Chemical profiling of the Arctic sea lettuce *Ulva lactuca* (Chlorophyta) mass-cultivated on land under controlled conditions for food applications. [Food Chemistry, 341 (2021) 127999]. Food Chem. 347(129059):129059. doi: 10.1016/j.foodchem.2021.129059.[PMC][33465689]

Rubino C. 2005. Reduplication: form, function and distribution. In: Hurch B, Mattes V, editors. Studies on reduplication. Berlin (Germany): Mouton de Gruyter. p. 11–29.

Saleeby NM. 1908. The History of Sulu. Manila (Philippines): Bureau of Printing.

Santelices B, González V, Beltrán J, Flores V. 2017. Coalescing red algae exhibit noninvasive, reversible chimerism. J Phycol. 53(1):59–69. doi:10.1111/jpy.12476

Santiañez WJE, Wynne MJ. 2020. Establishment of *Mimica* gen. nov. to accommodate the anaxiferous species of the economically important red seaweed *Eucheuma* (Solieriaceae, Rhodophyta). Phytotaxa 439(2):167–170. doi:10.11646/phytotaxa.439.2.8

Schmidtchen L, Roleda MY, Majschak JP, Mayser M. 2022. Processing technologies for solid and flexible packaging materials from macroalgae. Algal Res. 61:102300. doi:10.1016/j.algal.2021.102300

Smýkal P, Nelson M, Berger J, Von Wettberg E. 2018. The impact of genetic changes during crop domestication. Agronomy 8(7):119. doi:10.3390/agronomy8070119

Surya I, Chong EWN, Abdul Khalil HPS, Funmilayo OG, Abdullah CK, Sri Aprilia NA, Olaiya NG, Lai TK, Oyekanmi AA. 2021. Augmentation of physico-mechanical, thermal and biodegradability performances of bio-precipitated material reinforced in *Eucheuma cottonii* biopolymer films. J Mater Res Technol. 12:1673–1688. doi:10.1016/j.jmrt.2021.03.055

Suyo JGB, Le Masson V, Shaxson L, Luhan MRJ, Hurtado AQ. 2021. Navigating risks and uncertainties: Risk perceptions and risk management strategies in the Philippine seaweed industry. Mar Policy. 126:104408. doi:10.1016/j.marpol.2021.104408

Tan J, Lim PE, Phang SM, Rahiman A, Nikmatullah A, Sunarpi H, Hurtado AQ. 2014. *Kappaphycus malesianus* sp. nov.: a new species of *Kappaphycus* (Gigartinales, Rhodophyta) from Southeast Asia. J Appl Phycol. 26(2):1273–1285. doi:10.1007/s10811-013-0155-8

Tan J, Lim P-E, Phang S-M, Hong DD, Sunarpi H, Hurtado AQ. 2012. Assessment of four molecular markers as potential DNA barcodes for red algae Kappaphycus Doty and Eucheuma J. Agardh (Solieriaceae, Rhodophyta). PLoS One 7(12):e52905. doi:10.1371/journal.pone.0052905

Tano SA, Halling C, Lind E, Buriyo A, Wikström SA. 2015. Extensive spread of farmed seaweeds causes a shift from native to non-native haplotypes in natural seaweed beds. Mar Biol. 162(10):1983–1992. doi:10.1007/s00227-015-2724-7

Teo BSX, Gan RY, Abdul Aziz S, Sirirak T, Mohd Asmani MF, Yusuf E. 2021. In vitro evaluation of antioxidant and antibacterial activities of *Eucheuma cottonii* extract and its in vivo evaluation of the wound-healing activity in mice. J Cosmet Dermatol. 20(3):993–1001. doi:10.1111/jocd.13624

Thien VY, Yong WTL, Anton A, Chin GJWL. 2020. A multiplex PCR method for rapid identification of commercially important seaweeds *Kappaphycus alvarezii*, *Kappaphycus striatus* and *Eucheuma denticulatum* (Rhodophyta, Solieriaceae). Reg Stud Mar Sci. 40:101499. doi:10.1016/j.rsma.2020.101499

Trono GC, Largo DB. 2019. The seaweed resources of the Philippines. Bot Mar. 62(5):483–498. doi:10.1515/bot-2018-0069

Trono GC, Lluisma Ao, Montaño MNE. 2000. Primer on farming and strain selection of Kappaphycus and Eucheuma in the Philippines. Quezon City (Philippines): PCAMRD, UPMSI and UNDP.

Turland NJ, Wiersema Jh, Barrie Fr, Greuter W, Hawksworth Dl, Herendeen Ps, Knapp S, Kusber W-H, Li D-Z, Marhold K, et al. 2018. International code of nomenclature for algae, fungi, and plants (Shenzhen Code) adopted by the Nineteenth International Botanical Congress Shenzhen China, July Regnum Vegetabile 159. Glashütten (Germany): Koeltz Botanical Books. doi: 10.12705/Code.2018.

Usandizaga S, Valenzuela P, Gaitán-Espitia JD, Destombe C, Guillemin ML. 2021. Reproductive effort in the domesticated red alga *Agarophyton chilense*: differences between farms and natural populations. J Appl Phycol. 33(2):1149–1156. doi:10.1007/s10811-020-02325-8

Valderrama D, Cai J, Hishamunda N, Ridler N. 2013. Social and economic dimensions of carrageenan seaweed farming. Rome (Italy): FAO Food and Agriculture Organization of the United Nations. Fisheries and aquaculture technical paper no. 580. [accessed 2021 Aug 8]. http://www.fao.org/3/i3344e/i3344e.pdf.

Valero M, Guillemin M-L, Destombe C, Jacquemin B, Gachon CMM, Badis Y, Buschmann AH, Camus C, Faugeron S. 2017. Perspectives on domestication research for sustainable seaweed aquaculture. Pip. 4(1):33–46. doi:10.1127/pip/2017/0066

van der Meer JP. 1979. Genetics of *Gracilaria tikvahiae* (Rhodophyceae). VI. Complementation and linkage analysis of pigmentation mutants. Can J Bot. 57(1):64–68. doi:10.1139/b79-013

Velasquez GT. 1977. History on the local uses of seaweeds. Sci Rev. 18:20–24.

Wade R, Augyte S, Harden M, Nuzhdin S, Yarish C, Alberto F. 2020. Macroalgal germplasm banking for conservation, food security, and industry. PLoS Biol. 18(2):e3000641. doi:10.1371/journal.pbio.3000641

Wambugu PW, Henry R. 2022. Supporting *in situ* conservation of the genetic diversity of crop wild relatives using genomic technologies. Mol Ecol. doi:10.1111/mec.16402

Wang Y, Wang Y, Sun X, Caiji Z, Yang J, Cui D, Cao G, Ma X, Han B, Xue D, et al. 2016. Influence of ethnic traditional cultures on genetic diversity of rice landraces under on-farm conservation in southwest China. J Ethnobiol Ethnomed. 12(1):51. doi: 10.1186/s13002-016-0120-0.

Ward GM, Faisan JP, Cottier-Cook EJ, Gachon C, Hurtado AQ, Lim PE, Matoju I, Msuya FE, Bass D, Brodie J. 2020. A review of reported seaweed diseases and pests in aquaculture in Asia. J World Aquacult Soc. 51(4):815–828. doi:10.1111/jwas.12649

Ward GM, Kambey CSB, Faisan JP, Tan PL, Daumic CC, Matoju I, Stentiford GD, Bass D, Lim PE, Brodie J, Poong SW. 2022. Ice-ice disease: an environmentally and microbiologically driven syndrome in tropical seaweed aquaculture. Rev Aquacult. 14(1):414–439. doi:10.1111/raq.12606

Watanabe MM, 2005. Cultures as a means of protecting biological resources: Ex situ conservation of threatened algal species. In Anderson RJ, editor. Algal Culturing Techniques. Burlington: Elsevier Academic Press. p. 419–428.

Xiao X, Agustí S, Yu Y, Huang Y, Chen W, Hu J, Li C, Li K, Wei F, Lu Y, et al. 2021. Seaweed farms provide refugia from ocean acidification. Sci Total Environ. 776:145192. doi:10.1016/j.scitotenv.2021.145192

Yang H, Huo Y, Yee JC, Yarish C. 2021. Germplasm cryopreservation of macroalgae for aquaculture breeding and natural resource conservation: A review. Aquaculture 544:737037. doi:10.1016/j.aquaculture.2021.737037

Zuccarello GC, Critchley AT, Smith J, Sieber V, Lhonneur GB, West JA. 2006. Systematics and genetic variation in commercial *Kappaphycus* and *Eucheuma* (Solieriaceae, Rhodophyta). J Appl Phycol. 18(3–5):643–651. doi:10.1007/s10811-006-9066-2