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The Diversity of Eucheumatoid Seaweed Cultivars in the Philippines

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► **To cite this version:**

Richard V Dumilag, Zae-Zae A Aguinaldo, Bea A Crisostomo, Lourie Ann R. Hinaloc, Lawrence M Liao, et al.. The Diversity of Eucheumatoid Seaweed Cultivars in the Philippines. *Reviews in Fisheries Science & Aquaculture*, 2023, 31 (1), pp.47-65. 10.1080/23308249.2022.2060038 . hal-04061130

HAL Id: hal-04061130

<https://hal.science/hal-04061130>

Submitted on 6 Apr 2023

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3 **1 Eucheumatoid seaweed cultivar diversity in the Philippines**
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5253 52
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55 53 Word count: 3597
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1
2
3 54 **Abstract**
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5 55 Collectively known as eucheumatoids, *Eucheuma denticulatum*, *Kappaphycus*
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8 56 *alvarezii*, *K. malesianus* and *K. striatus* are the main farmed seaweed species in the
9
10 57 Philippines. The success of seaweed farming for over five decades in the country is
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13 58 due, in part, to the high diversity of cultivars maintained by the Filipino farmers.
14
15 59 Notwithstanding the fact that many eucheumatoid cultivars are presently (and
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18 60 consistently) recognised by the Filipino farmers, there has been no attempt to
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20 61 summarise the current state of the farmer's knowledge about their diversity.
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23 62 Hence, a review is presented of the taxonomy, diversity, distribution and
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25 63 conservation strategies of eucheumatoid cultivars based on farmers' knowledge
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27 64 and genetic identification in the Philippines. The diverse cultivars identified in this
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30 65 study suggest that the Filipino farmers possess important traditional knowledge
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32 66 that can be useful for future crop selection and breeding.
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39 69 **Keywords:** carrageenophytes, distribution, ethnobotany, seaweed farming,
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42 70 taxonomy, traditional knowledge
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78 **Introduction**

79 Whilst seaweed use dates to the Neolithic (Dillehay et al. 2008), it is only in the
80 last five decades that its domestication has been commercially exploited,
81 particularly in the tropics (Doty 1973; Doty and Alvarez 1973; Parker 1974).
82 Seaweeds currently comprise a significant portion of the world's aquaculture
83 production, with over 32 million tonnes of fresh weight harvested in 2018 (FAO
84 2020; Chopin and Tacon 2021). Evolving pressures brought by diseases and pests
85 and growing environmental challenges (changing climate, pollution, coastal use
86 conflicts, etc.) bring into question the foundation of today's farming systems (Naylor
87 et al. 2021; Ward et al. 2020, 2021). Sustainable and high yield production has,
88 however, become a critical factor in the successful development of this global
89 industry.

90
91 The term 'phyconomy' was coined by Hurtado et al. (2019) to describe a unified
92 concept of extensive and sustainable seaweed farming for livelihood purposes.
93 Coupled with economic benefits are the legacies that phyconomy has rendered to
94 human histories, especially on redefining demographics of coastal settlements
95 (Nimmo 1986; Nor et al. 2017; Hussin and Khoso 2021) and promoting women's
96 roles in the industry (Periyasamy et al. 2014; Valderrama et al. 2013; Msuya and
97 Hurtado 2017; Larson et al. 2021). Today, seaweed farming is not only seen as a
98 food crop enterprise, but also as a multi-use system with significant potential for
99 carbon sequestration to mitigate ocean acidification, (Duarte et al. 2017; Froehlich et
100 al. 2019; Xiao et al. 2021), aid in eutrophic environment restoration (Zhang et al.

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3 101 2019; Roleda and Hurd 2019) and provide an eco-engineering solution for problems
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5 102 on urban shorelines (Heery et al. 2020).
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10 104 Species belonging to the rhodophyte genera *Kappaphycus* and *Eucheuma*,
11
12 105 collectively known as eucheumatoids, were initially cultivated in the Philippines to
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14 106 support an industry suffering from the commercial decline in the amount and quality
15
16 107 of carrageenan-producing crops (viz. *Chondrus crispus*) from the wild (Blanchetti-
17
18 108 Revelli 1995; Kraft 1997). Carrageenan is a food ingredient composed of sulfated
19
20 109 hydrocolloid molecules that are added to other foods as gelling, thickening and
21
22 110 stabilising agents, and are proven safe for human use (McKim et al. 2019).
23
24 111 Carrageenan is also recently seen as an effective encapsulating agent (helps
25
26 112 improve drug release) used for viral infection treatments (Derby et al. 2018; Jang et
27
28 113 al. 2021). Selection of fast-growing clones from wild stocks by pioneering Filipino
29
30 114 farmers (Doty and Alvarez 1975) and the successful establishment of farms in the
31
32 115 1970s led to the rapid expansion of seaweed farming in the Philippines (Trono and
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34 116 Largo 2019, see also Figure 1). There are currently 58 coastal provinces engaged in
35
36 117 seaweed farming in the country (Figure 1). Local and seasonal changes in
37
38 118 environmental conditions and farming problems can influence crop production and
39
40 119 as a result, a number of local farming customs have been developed including
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42 120 selection of cultivars (i.e. after exchange of cultivars between the Filipino farmers),
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44 121 cropping calendars (i.e. selecting growing season and harvesting time to maximise
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46 122 production), type of planting and drying methods (Quiaoit et al. 2016; Hurtado et al.
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48 123 2019).
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3 125 The selected eucaumatoid cultivars typically exhibit traits that favour high biomass
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5 126 production and qualities, such as carrageenan yield and gel strength (Trono et al.
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8 127 2000; Phang et al. 2010; Parenrengi et al. 2020). These traits are either pre-existing
9
10 128 (from their evolutionary history) or have arisen during the domestication process
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13 129 through breeding and artificial selection (Valero et al. 2017). It has been suggested
14
15 130 that a classification system based on the farmers' knowledge can serve as a
16
17 131 starting point for assessing the diversity of crop cultivars, such as observed in
18
19 132 maize (Hopkins 2006), potato (De Haan et al. 2007), rice (Wang et al. 2016; Loko
20
21 133 et al. 2021) and yam (Asfaw et al. 2021). For eucaumatoid cultivars, improving
22
23 134 knowledge on genetic and phenotypic diversity could help identify suitable
24
25 135 candidates for strain amelioration and increase their resilience to disease and pest
26
27 136 outbreaks (Valero et al. 2017; Ward et al. 2020, 2021; Hinaloc and Roleda 2021).
28
29 137 This diversity, in combination with knowledge on farming practices can also be
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31 138 used as a valuable reference in national planning initiatives in providing effective
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33 139 policy frameworks to sustainably develop the industry (Cottier-Cook et al. 2016;
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35 140 Brakel et al. 2021).

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44 142 The seaweed cultivars initially identified for commercial exploitation in the Philippines
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46 143 (Doty 1973; Doty and Alvarez 1973; Parker 1974) have now been distributed
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48 144 worldwide (Zuccarello et al. 2006; Neish et al. 2017; Kelly et al. 2020). Over five
49
50 145 decades of seaweed farming, Filipino farmers have accumulated extensive
51
52 146 knowledge on farming practices and cultivar selection (Mateo et al. 2021; Suyo et
53
54 147 al. 2021). Despite this long history of seaweed farming, the diversity and
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56 148 distribution of seaweed cultivars in the country have not been thoroughly
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3 149 reviewed. We aim to present the first detailed assessment of the taxonomy,
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5 150 diversity, distribution of eucheumatoid cultivars based on farmers' knowledge, as
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8 151 well as their genetic differentiation and conservation strategies in the Philippines.
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13 153 ***Literature review***

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15 154 A systematic review was conducted of peer-reviewed journal articles, local books
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17 155 and unpublished lists that mention local names of eucheumatoid cultivars identified
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20 156 by the Filipino farmers. We determined which species these cultivars belonged to
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22 157 by either consulting the farmers directly or, if previously reported, by assessing the
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25 158 original reporting sources. We determined which species were recognized by each
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27 159 of the sourced authors, local names that were used by other authors to refer to a
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30 160 similar cultivar name, cultivar name etymologies and their distribution in the
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32 161 Philippines. Translation and interpretation of the meanings of the local names were
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34 162 provided by the farmers and expert native speakers. The reported *cox2-3*
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37 163 intergenic spacer barcodes of eucheumatoids from the Philippines were also
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39 164 gathered from existing literature.
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44 166 ***Nomenclatural note***

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46 167 The terms *cultivar*, *strain* and *variety* are commonly used interchangeably in
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48 168 differentiating morphological diversities among algae, particularly in seaweed
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51 169 crops. The term *strain* may either refer to a wild or cultivated eucheumatoid. The
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54 170 name of a strain can be derived from a name based on farmer's knowledge or a
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56 171 name based on investigator's desired assignment (of a replicate) generally used for
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58 172 experimental studies (see Hayashi et al. 2007; Mendoza et al. 2002; Ali et al.
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3 173 2017). In this review, only the term *cultivar* will refer to the seaweed crops grown
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6 174 and named by the farmers in accord with the definition of the International Code
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8 175 of Nomenclature for Cultivated Plants (Brickell et al. 2016). Likewise, as specified
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10 176 in the International Code of Nomenclature for Algae, Fungi, and Plants (Turland et
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12
13 177 al. 2018), the use of the term *variety* in this study will pertain to a variation below
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15 178 species level effected by a valid taxonomic description.
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180 ***Taxonomy of seaweed cultivars in the Philippines***

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

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191 Although radiation within the tribe has been hypothesised to have occurred in the
192 ancient Tethys Ocean prior to continental shifts some 100 MYA (Fredericq et al.
193 1999), the highest eucheumatoid diversity is currently reported in the Indo-Pacific
194 (Doty 1988; Hurtado et al. 2016). Members of the eucheumatoids are found growing
195 in a variety of habitats from shallow reefs to depths of over 45 m (Doty 1973). As a
196 consequence of intentional transplantations that have taken place for farming uses,

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3 197 eucheumatoids are also now established in many non-indigenous regions
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6 198 characterised by warm waters (Kelly et al. 2020; Brakel et al. 2021).
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8 199
9
10 200 *Eucheuma denticulatum*, *Kappaphycus alvarezii*, *K. malesianus* and *K. striatus*
11
12 201 (Figure 2-3) are among the most farmed eucheumatoids in the Philippines.
13
14 202 Morphologically they are characterised by a set of several overlapping characters
15
16 203 (Doty 1988; Tan et al. 2014; Hurtado et al. 2016) that make definitive identification
17
18 204 difficult at times. Progress on their phylogeny and taxonomy has been enhanced by
19
20 205 the use of molecular data (Zuccarello et al. 2006; Dumilag et al. 2016a; Lim et al.
21
22 206 2017). Despite the considerable morphological diversity that domesticated
23
24 207 eucheumatoids display, there are only four taxonomic varieties recognised. These
25
26 208 include *Eucheuma denticulatum* var. *endong* (Ganzon-Fortes et al. 2012),
27
28 209 *Kappaphycus alvarezii* var. *alvarezii*, *Kappaphycus alvarezii* var. *tambalangii* and
29
30 210 *Kappaphycus alvarezii* var. *ajakii-assii* (Liao 1996). Except for *K. alvarezii* var.
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32 211 *alvarezii* (type locality is in Malaysia) the Philippines is the type locality of all these
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34 212 varieties (Doty 1985).
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214 ***Commercial nomenclature in eucheumatoids***

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46 215 Far predating the advent of their domestication, the use of seaweeds as food in the
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48 216 Philippines has a history dating back to pre-colonial occupation of the islands
49
50 217 (Velasquez 1977). The earliest Philippine record of seaweed as a trade commodity
51
52 218 began in the seventeenth century when *Agal-agal*, a local name for
53
54 219 eucheumatoids, was recorded as a major food product in the early Sulu enterprises
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56 220 and as an exchange commodity for imports from China (Saleeby 1908; Fry 1970).
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3 221 *Agal-agal* has since remained a highly sought after product, with deep cultural
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6 222 value among communities in the southern Philippine Sulu Archipelago (Dumilag
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8 223 2019).
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12
13 225 Stable nomenclature for products is necessary for communication and record
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15 226 keeping regarding biological resources and their acceptance for trading purposes.
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17 227 The standard use of names is also fundamental to various scientific applications.
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20 228 Seen as such is the possible mixing of carrageenan extracts from two (or more)
21
22 229 eucheumatoid species belonging to different genera, which may lead to ineffective
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24 230 process of extraction, hence, lowering quality of the final product (see Ganzon-
25
26 231 Fortes et al. 2012). Since the 1980s, taxonomists have been aware of the significant
27
28 232 confusion that exists in relation to the correct scientific epithets for commercially
29
30 233 important seaweeds (Bolton 2020), including of eucheumatoids (Table 1). The
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32 234 situation is compounded, as some investigators continue to publish their work using
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34 235 outdated nomenclature, e.g. the use of "*Eucheuma cottonii*" (see Surya et al. 2021,
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36 236 Teo et al. 2021), "*Eucheuma spinosum*" (see Bouanati et al. 2020, Gurav et al.
37
38 237 2021) and even a non-existent taxonomic combination, "*Kappaphycus spinosum*"
39
40 238 (see Adharini et al. 2019). This highlights the importance of proactive assessment
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42 239 and intervention by journal editors and expert reviewers, particularly in applied
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44 240 sciences where reports of invalid species names are prevalent (c.f. Roleda et al.
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46 241 2021b; Roleda and Heesch 2021) and are most often left uncorrected, except in
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48 242 rare occasion (e.g. Roleda et al. 2021c).
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245 **Diversity of eucheumatoid cultivars based on farmer's knowledge**

246 Sixty-five eucheumatoid cultivars are identified and named in the Philippines,
247 largely based on morphology as seen by Filipino farmers (Table 2). Based on our
248 analysis, 27 cultivars are identified as *K. alvarezii*, 15 as *K. striatus*, six as *E.*
249 *denticulatum* and three as *K. malesianus*. However, an additional 14 cultivar names
250 require further investigation to determine what species they belong to. The
251 majority (83%) of cultivar names are identified as a single scientific species whilst
252 others are attributed to more than one species. For example, the cultivar *Aring-*
253 *Aring* is represented by all three farmed *Kappaphycus* species while the cultivars
254 *Cottonii* (or *Katunay*) and *Sacol* may be attributed to *K. alvarezii* or *K. striatus*.
255 Even the *Spinsum*, the most common cultivar name for *E. denticulatum*, can be
256 referred to as a cultivar of *K. alvarezii* (Table 2).

257
258 Local cultivars are structurally named, using either a unitary (single word) or binary
259 (two words) format. Unitary names predominate, constituting 61 of the 65 cultivars
260 identified by farmers. Of these, 82.54% are derived from local dialects, whilst the
261 others are adapted from English. Some unitary names are formed through full
262 lexical reduplication (i.e. repeating names such as *Milyon-Milyon*, *Kab-Kab*, *Butay-*
263 *Butay*), a familiar word formation process among Philippine dialects (Blake 1917;
264 Rubino 2005; Mattes 2014). With the exception of the cultivars *Ara Mina* and *Kuku*
265 *Belleh*, the others have binary names adapted from English (e.g. *Nile Green*,
266 *Sweet Loving* and *Seven Colours*).

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3 268 The translation of names reveals that most cultivar names match certain aspects of
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5 269 the seaweed. The name derivation is based on several attributes or objects, such
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8 270 as the description of the branching pattern (e.g. *Endong*, *Kab-Kab*, and *Repolyo*),
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10 271 colour (e.g. *Nile Green*, *Pula-Pula* [red], and *Seven Colours*), source locality (e.g.
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12 272 *Digos*, *Sacol*, and *Zamboanga*) and the person who discovered them (e.g. *Aring-*
13
14 273 *Aring* and *Tambalang*). Only a few names indicate no clear reference as to the
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16 274 characteristic or history of the origin of the cultivar. For example, some cultivars
17
18 275 are named from popular personalities (e.g. *Ara Mina* and *Marimar*), or random
19
20 276 brand names (e.g. *Duralex*, *Bitsi-Bitsi* from Mitsubishi, and *Vanguard*). Two
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22 277 cultivars have unknown etymologies (i.e. *Sweet Loving* and *Way-Way*).
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30 279 Eighteen cultivars have variant names (Table 2). The cultivar *Tambalang* (Figure
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32 280 3C) has the greatest number of variants with 14 name combinations. Colour is the
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34 281 most common trait attributed to a variant name. Brown, green, red are the
35
36 282 dominant colours of seaweed cultivars in the Philippines (Figure 4). *Kappaphycus*
37
38 283 *striatus* exhibit the most variability in this respect. The *K. striatus* cultivar named
39
40 284 *Seven Colours* (only recorded in Tawi-Tawi, southern Philippines to date, see
41
42 285 Figure 3B) however, cannot be categorised as one discrete colour, since the thallus
43
44 286 is multi-coloured ranging from yellow, to green to brown. Several individuals of the
45
46 287 *E. denticulatum* cultivar *Spinsum* (Figure 2A) exhibit a bi-coloured (brown and
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48 288 red) thalli. This colour pattern is observed in specimens sampled from varying
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50 289 environments, indicating that it may have a genetic basis, as previously shown in
51
52 290 *Gracilaria* species (e.g. van der Meer 1979; Plastino et al. 1999; Marchi and
53
54 291 Plastino 2020). Accordingly, the green and brown colour variants of *K. alvarezii*
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292 cultivar *Burikat* and *K. striatus* cultivar *Kab-Kab* (Figure 3C) are each represented
293 by differing *cox2-3* haplotypes (Dumilag et al. 2016, see Table 2). Other variant
294 identification features are based on a combination of other cultivar names (e.g.
295 *Tambalang Giant*, *Tambalang Sacol*, *Sacol Vanguard*) or size differences (e.g.
296 *Tambalang diki* means small and *Tambalang heya* means big).

297

298 ***Seaweed cultivar distribution in the Philippines***

299 The eucaematoid species and the corresponding distribution of cultivars in the
300 Philippines are appeared to be random (Figure 5, Table 2). Twenty-six of the
301 named cultivars are recorded in multiple areas throughout the country. Thirty-nine
302 cultivars are exclusive to a single area, particularly in Regions IX and XIII, and
303 BARMM. A highest number of cultivars are recognised within the larger farming
304 areas, including Tawi-Tawi (BARMM, n=30), Zamboanga City and Zamboanga del
305 Sur (Region IX, n=17 and n=12 respectively), and Palawan (Region IV-B, n=11).
306 *Spinsum* (Figure 2A) is the most widely distributed cultivar of *E. denticulatum*,
307 whereas, the *Cottonii*, *Tambalang* (Figure 2C) and *Giant* (Figure 2F) is accounted
308 for the three most common *K. alvarezii* cultivars whilst *Sacol* (Figure 3A) and
309 *Vanguard* are the most common for *K. striatus*. *Kappaphycus malesianus* has the
310 most restricted distribution, only being reported in Tawi-Tawi with three locally
311 recognized cultivars, *Aring-Aring* (Figure 3D), *Halaw* (Figure 3E), *Kuku Belleh'*
312 (Figure 3F). Nearly all cultivars that have yet to be identified by scientific names
313 are only known from their respective areas, mostly from southern Mindanao.

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3 315 The wide distribution of farmed *K. alvarezii* and *K. striatus* in the Philippines is due
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5 316 to the higher demand for their extracts (i.e. kappa-carrageenan as compared with
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7
8 317 the iota type) and its reputation for greater environmental adaptability (Glenn and
9
10 318 Doty 1992; Bindu and Levine 2011). The widespread use of cultivar names, e.g.
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12 319 *Spinsum*, *Tambalang* and *Cottonii*, is most likely related to the free exchange of
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14 320 seedstocks across the country (see Quiaoit et al. 2016). Reciprocal transfers of
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16 321 cultivars follow traditional practice of solidarity, as they occur between relatives,
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18 322 friends, or neighbours usually within similar ethnic groups (R. Dumilag, personal
19
20 323 observation). Seedstocks are also exchanged after loss of crops (e.g. by typhoons
21
22 324 or diseases and pests), during farm expansion, or when testing other cultivars for
23
24 325 better yields. Government interventions also play an important role in the supply of
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26 326 seedstocks among farmers in the Philippines (Suyo et al. 2020). Farmers receive
27
28 327 seaweed cultivars from the government agencies such the Department of Science
29
30 328 and Technology (DOST), Bureau of Fisheries and Aquatic Resources (BFAR),
31
32 329 Department of Trade and Industry (DTI) and the respective local government units
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34 330 (Quiaoit et al. 2016). It is also possible that the same cultivar names have been
35
36 331 given to distinct farmed genotypes in different areas and that information based on
37
38 332 farmer knowledge underestimate morphological and genetic diversity at the
39
40 333 national or regional level (as in case study in yam by Asfaw et al. 2021).
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335 ***Genetic diversity of Philippine seaweed cultivars***

336 Information on genetic diversity among Philippine seaweed cultivars is still
337 incomplete, with only 25 cultivars sequenced for mitochondrial markers. The most
338 recent analysis based on the *cox2-3* spacer revealed that Philippine cultivars include

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3 339 seven haplotypes (Roleda et al. 2021a). A survey of mitochondrial *cox2-3* spacer
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5 340 sequences revealed between one to three farmed haplotypes per species: *E.*
6
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8 341 *denticulatum* (haplotype 13), *K. alvarezii* (haplotypes 3, KALV-1 and KALV-2), *K.*
9
10 342 *malesianus* (haplotype MY216), and *K. striatus* (haplotypes 89 and 117). There is no
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12
13 343 clear correspondence between mitochondrial haplotypes, morphology and cultivar
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15 344 names. Notwithstanding this apparently high genetic similarity and lack of
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18 345 concordance between haplotypes and phenotypes, the morphological features of the
19
20 346 different cultivars still allow their differentiation. The differences also appear to be
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22
23 347 fairly stable in different environmental conditions, which explains how farmers are
24
25 348 able to recognise each cultivars in the field. This observable phenotypic diversity
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27 349 raises the possibility that more informative genetic markers would be able to
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29
30 350 genetically differentiate between these cultivars (see Thien et al. 2020; Risjani and
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32 351 Abidin 2020). As can also be applied for eucaumatoid cultivars, high throughput
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34 352 sequencing and single nucleotide polymorphisms (SNPs) have been helpful in
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36
37 353 exploring the neutral and functional genetic diversity among crops: allowing
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39 354 detection of misclassified cultivars, examining reduction of genetic diversity and
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42 355 accumulation of deleterious alleles during selection steps (O'Connor et al. 2019;
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44 356 Diaz-Garcia et al. 2020).

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48
49 358 One of the most common impacts of intensive cultivation is the severe reduction of
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51 359 genetic diversity in crops due to recurrent bottlenecks. The narrowing of the
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54 360 genetic basis begins with selection of a few strains of interest from wild
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56 361 environments and is intensified during the development of elite cultivars through
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59 362 intensive breeding programs. The propagation based on asexual reproduction can
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3 363 dramatically affect crop genetic diversity (McKey et al. 2010; Meyer et al. 2012;
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5 364 Smýkal et al. 2018). In potatoes and yam for example, farming based on asexual
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8 365 reproduction has led to a severe reduction of genetic diversity and an accumulation
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10 366 of deleterious alleles (Ramu et al. 2017; Pandey et al. 2021). Albeit the history of
11
12 367 domestication is more recent in seaweeds, typical hallmarks of impact of extensive
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14 368 use of vegetative propagation in farms, are very low levels of clonal variation, life
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16 369 cycle disruption and reduction of fertility as has been detected in the red alga
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18 370 *Agarophyton chilense* (Guillemin et al. 2008; Usandizaga et al. 2021). The problem
19
20 371 could be especially acute in eucheumatoid farms where cultivation from vegetative
21
22 372 thalli has led to the wide use of mitochondrially similar haplotypes around the
23
24 373 world (Zuccarello et al. 2006). These farmed haplotypes have spread to adjacent
25
26 374 areas both in the Philippines and in regions where these cultivars have been
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28 375 introduced (Halling et al. 2013; Tano et al. 2015; Dumilag et al. 2016b).
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32 377 High genetic and phenotypic diversity is expected in areas of crop origin (e.g.
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34 378 Hardigan et al. 2017). In the Philippines, a number of natural populations of
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36 379 eucheumatoids are located near the farms and gene flows probably occurs
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38 380 between domesticated and their wild populations (R. V. Dumilag, personal
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40 381 observation). Such condition can help delay the genetic diversity loss during
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42 382 domestication allowing introduction of new alleles at each generation even in
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44 383 highly asexually cultivated crops (Elias et al. 2001). Exchange of cultivars among
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46 384 Filipino farmers could also help to maintain potentially high population sizes, or
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48 385 genetic variants in multiple populations, but only through vegetative propagation.
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50 386 Introgression of new alleles in eucheumatoid crops due to natural crosses with
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3 387 individuals from nearby natural populations or distinct cultivars introduced from
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5 388 other regions may generate new genotypic combinations and potentially superior
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8 389 cultivars without the burden of performing costly breeding effort (Pautasso et al.
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10 390 2012; Labeyrie et al. 2016). The continuous discovery of new eucheumatoid
11
12 391 haplotypes demonstrates that high genetic diversity available in both farms and
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14
15 392 natural populations is still uncovered in the Philippines (Dumilag et al. 2016a,
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17 393 2016b, 2018; Roleda et al. 2021). It is therefore imperative to further explore this
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20 394 untapped diversity and to create seedbanks from sites without cultivation activity.
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22 395 These strategies could mitigate the decline of genetic diversity and can provide
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24 396 access to extensive genes variants better adapted to unprecedented challenges of
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26 397 today's seaweed farming system. The high number of cultivars in the Philippines
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28 398 makes the region one of the best sites for the discovery of new cultivars that can
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30 399 be preserved and their economic potential explored in future crop selection and
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33 400 breeding programmes.
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402 **The way forward**

403 The extent to which the role of cultivar diversity can potentially contribute to
404 advancing seaweed aquaculture is still largely under researched. Given the need to
405 maintain cultivar diversity as a means of promoting resilience of seaweed crops to
406 disease and pests and the increasing use of carrageenan, particularly in emerging
407 products such as the medical (Pereira and Critchley 2020; Morokutti-Kurz et al.
408 2021) and bioplastics industry (Schmidtchen et al. 2021). New cultivars will likely
409 play a more important role in the future. Future studies on cultivar diversity would
410 benefit from greater integration of ethnophycology (the study of the relationship

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3 411 between seaweeds and people; see Brodie, 2010) on farming, as explicit
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6 412 consideration of how farmers perceive cultivar-level variability and integration of
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8 413 farmer knowledge and their acceptance are essential to produce and utilize new
9
10 414 cultivars.

11 415

12 13 14 15 416 **Funding**

16
17 417 This study was primarily supported by research fund from the United Kingdom
18
19 418 Research and Innovation–Global Challenges Research Fund (UKRI- GCRF)
20
21 419 ‘GlobalSeaweedSTAR’ Programme GSS/RF/015 (BB/P027806/1) awarded to RVD
22
23 420 and MYR. RVD, FDG and HARQ were respectively supported by the Department of
24
25 421 Science and Technology (DOST), Philippine Council for Agriculture, Aquatic and
26
27 422 Natural Resources Research and Development (PCAARRD) projects: Molecular
28
29 423 characterization, selection and production of high quality eucaumatoid cultivars in
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31 424 the Bangsamoro Autonomous Region in Muslim Mindanao, Field Testing of
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33 425 Laboratory-reared Seaweed Cultivars from PSU-MSL Culture Facilities in MIMAROPA
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35 426 Region and Seaweed Area GIS-based Mapping: Production Support System for
36
37 427 Sustainable Seaweeds Farming in the Philippines. MYR was supported by the
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39 428 DOST-Balik Scientist Program (BSP) fellowship.
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45
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47
48
49
50
51
52
53
54
55
56
57
58
59
60

435 **References**

436

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

441

442 Ali MM, Sani MZB., Hi KK, Yasir SM, Critchley AT, Hurtado AQ. 2018. The
443 comparative efficiency of a brown algal-derived biostimulant extract (AMPEP), with
444 and without supplemented PGRs: the induction of direct, axis shoots as applied to
445 the propagation of vegetative seedlings for the successful mass cultivation of three
446 commercial strains of *Kappaphycus* in Sabah, Malaysia. J Appl Phycol. 30(6):1913–
447 1919. doi: <https://doi.org/10.1007/s10811-017-1366-1>.

448

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

452

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

456

457 Blake FR. 1917. Reduplication in Tagalog. Am J Philol. 38(4):425. doi:
458 <https://doi.org/10.2307/288967>.

1
2
3 459
4

5 460 Blanchetti-Revelli L. 1995. Canadian misfortunes and Filipino fortunes: the invention
6
7 of seaweed mariculture and the geographical reorganization of seaweed production.
8 461
9 In: McMichael P, editor. Food and agrarian orders in the world economy. Westport
10 462
11 (CT): Praeger Publishers. p. 97–112.
12 463
13
14

15 464
16

17 465 Bolton JJ. 2020. The problem of naming commercial seaweeds. J Appl Phycol.
18
19 32(2):751–758. doi: <https://doi.org/10.1007/s10811-019-01928-0>.
20 466
21

22 467
23

24 468 Borlongan IAG, Tibubos KR, Yunque DAT, Hurtado AQ, Critchley AT. 2011. Impact of
25
26 AMPEP on the growth and occurrence of epiphytic *Neosiphonia* infestation on two
27 469
28 varieties of commercially cultivated *Kappaphycus alvarezii* grown at different depths
29 470
30 in the Philippines. J Appl Phycol. 23(3):615–621. doi:
31 471
32 <https://doi.org/10.1007/s10811-010-9649-9>.
33 472
34
35

36 473
37

38 474 Bouanati T, Colson E, Moins S, Cabrera J-C, Eeckhaut I, Raquez J-M, Gerbaux P.
39
40 2020. Microwave-assisted depolymerization of carrageenans from *Kappaphycus*
41 475
42 *alvarezii* and *Eucheuma spinosum*: Controlled and green production of
43 476
44 oligosaccharides from the algae biomass. Algal Res. 51:102054. doi:
45 477
46 <https://doi.org/10.1016/j.algal.2020.102054>.
47 478
48
49

50 479
51

52 480 Brakel J, Sibonga RC, Dumilag RV, Montalescot V, Campbell I, Cottier-Cook EJ, Ward
53
54 G, Le Masson V, Liu T, Msuya FE, et al. 2021. Exploring, harnessing and conserving
55 481
56
57
58
59
60

- 1
2
3 482 marine genetic resources towards a sustainable seaweed aquaculture. *Plants People*
4 Planet. 3(4):337–349. doi: <https://doi.org/10.1002/ppp3.10190>.
5
6 483
7
8 484
9
10 485 Brickell CD, Alexander C, Cubey JJ, David JC, Hoffman MHM, Leslie AC, Malécot V,
11
12 486 Jin, X, editors. 2016. International code of nomenclature for cultivated plants, ninth
13
14 487 edition. *Scripta Horticulturae* 18. International Society for Horticultural Science.
15
16 488
17
18 489 Brodie, J. 2010. Global Seaweed Network: a global seaweed strategy. [accessed
19
20 490 2021 September 28]. [https://www.nhm.ac.uk/our-science/our-](https://www.nhm.ac.uk/our-science/our-work/biodiversity/global-seaweed-network.html)
21
22 491 [work/biodiversity/global-seaweed-network.html](https://www.nhm.ac.uk/our-science/our-work/biodiversity/global-seaweed-network.html).
23
24 492
25
26 493 Chopin T, Tacon AGJ. 2021. Importance of seaweeds and extractive species in global
27
28 494 aquaculture production. *Rev Fish Sci Aquac.* 29(2):139–148. doi:
29
30 495 <https://doi.org/10.1080/23308249.2020.1810626>.
31
32 496
33
34 497 Cottier-Cook EJ, Nagabhatla N, Badis Y, Campbell M, Chopin T, Dai W, Fang J, He P,
35
36 498 Hewitt C, Kim GH. 2016. Safeguarding the future of the global seaweed aquaculture
37
38 499 industry. Hamilton (ON/Canada): United Nations University and Scottish Association
39
40 500 for Marine Science. Policy brief. [accessed 2021 Aug 08].
41
42 501 <https://www.sams.ac.uk/t4-media/sams/pdf/globalseaweed-policy-brief.pdf>.
43
44 502
45
46 503 de Haan S, Bonierbale M, Ghislain M, Núñez J, Trujillo G. 2007. Indigenous
47
48 504 biosystematics of Andean potatoes: Folk taxonomy, descriptors and nomenclature.
49
50 505 *Acta Hortic.* (745):89–134. doi: <https://doi.org/10.17660/ActaHortic.2007.745.4>.
51
52
53
54
55
56
57
58
59
60

1
2
3 506
4

5 507 Derby N., Lal M, Aravantinou M, Kizima L, Barnable P, Rodriguez A, Lai M,
6
7 508 Wasenberg A, Ugaonkar S, Levendosky K, Mizenina O, Kleinbeck K, Lifson JD, Peet
8
9 509 MM, Lloyd Z, Benson M, Heneine W, O’Keefe BR, Robbiani M, Martinellu E,
10
11 510 Grasperge B, Blanchard J, Gettie A, Teleshova N, Fernández-Romero JA, Zydowsky
12
13 511 TM. 2018. Griffithsin carrageenan fast dissolving inserts prevent SHIV HSV-2 and
14
15 512 HPV infections in vivo. Nat Commun 9:3881. doi: [https://doi.org/10.1038/s41467-](https://doi.org/10.1038/s41467-018-06349-0)
16
17 513 [018-06349-0](https://doi.org/10.1038/s41467-018-06349-0).

18
19
20
21
22 514

23
24 515 Diaz-Garcia L, Covarrubias-Pazarán G, Johnson-Cicalese J, Vorsa N, Zalapa J. 2020.
25
26 516 Genotyping-by-sequencing identifies historical breeding stages of the recently
27
28 517 domesticated American cranberry. Front Plant Sci. 11:607770. doi:
29
30 518 <https://doi.org/10.3389/fpls.2020.607770>.

31
32
33
34 519

35
36 520 Dillehay TD, Ramirez C, Pino M, Collins MB, Rossen J, Pino-Navarro JD. 2008. Monte
37
38 521 Verde: Seaweed, food, medicine, and the peopling of South America. Science.
39
40 522 320(5877):784–786. doi: <https://doi.org/10.1126/science.1156533>.

41
42
43
44 523

45
46 524 Doty MS. 1973. Farming the red seaweed, *Eucheuma*, for carrageenans.
47
48 525 Micronesica. 9:59–73.

49
50
51 526

52
53 527 Doty MS. 1985. *Eucheuma alvarezii*, sp. nov. (Gigartinales, Rhodophyta) from
54
55 528 Malaysia. In: Abbott IA, Norris JN, editors. Taxonomy of economic seaweeds: with
56
57
58
59
60

- 1
2
3 529 reference to some Pacific and Caribbean species. Vol. 1. La Jolla (CA): California Sea
4
5
6 530 Grant College Program. p. 37–45.
7
8 531
9
10 532 Doty MS. 1988. *Prodromus ad systematica Eucheumatoideorum*: a tribe of
11
12 533 commercial seaweeds related to *Eucheuma* (Solieriaceae, Gigartinales). In: Abbott
13
14 534 IA, editor. Taxonomy of economic seaweeds with reference to some Pacific and
15
16 535 Caribbean species. Vol. 2. La Jolla (CA): University of California. p. 159–207.
17
18 536
19
20 537 Doty MS. 1995. *Betaphycus philippinensis* gen. et sp. nov. and related species
21
22 538 (Solieriaceae, Gigartinales). In: Abbott IA, editor. Taxonomy of economic seaweeds
23
24 539 with reference to some Pacific and Caribbean species. Vol. 5. La Jolla (CA):
25
26 540 University of California. p. 237–245.
27
28 541
29
30 542 Doty M.S., Alvarez V.B. 1973. Seaweed farms: A new approach for U. S. industry. In:
31
32 543 Proceedings of 9th Annual Conference of the Marine Technology Society; 1973 Sept
33
34 544 10–12; Washington DC. p. 701–708.
35
36 545
37
38 546 Doty MS, Alvarez VB. 1975. Status, problems, advances, and economics of
39
40 547 *Eucheuma* farms. Mar Technol Soc J. 9:30–35.
41
42 548
43
44 549 Duarte CM, Wu J, Xiao X, Bruhn A, Krause-Jensen D. 2017. Can seaweed farming
45
46 550 play a role in climate change mitigation and adaptation? Front Mar Sci. 4:100. doi:
47
48 551 <https://doi.org/10.3389/fmars.2017.00100>.
49
50 552
51
52
53
54
55
56
57
58
59
60

- 1
2
3 553 Dumilag RV. 2019. Edible seaweeds sold in the local public markets in Tawi-Tawi,
4
5 554 Philippines. Philipp J Sci. 148:803–811.
6
7
8 555
9
10 556 Dumilag RV, Lluisma AO. 2014. Resolving the phylogenetic affinities of *Kappaphycus*
11
12 557 *inermis* within the genus *Kappaphycus* (Gigartinales, Solieriaceae) using
13
14 558 mitochondrial and plastid markers. Phytotaxa. 162(4):223 –231. doi:
15
16 559 <http://dx.doi.org/10.11646/phytotaxa.162.4.5>.
17
18 560
19
20 561 Dumilag RV, Orosco FL, Lluisma AO. 2016a. Genetic diversity of *Kappaphycus*
21
22 562 species (Gigartinales, Rhodophyta) in the Philippines. Syst Biodivers. 14(5):441–451.
23
24 563 doi: <https://doi.org/10.1080/14772000.2016.1157643>.
25
26 564
27
28 565 Dumilag RV, Salvador RC, Halling C. 2016b. Genotype introduction affects population
29
30 566 composition of native Philippine *Kappaphycus* (Gigartinales, Rhodophyta). Conserv
31
32 567 Genet Resour. 8(4):439–441. doi: <https://doi.org/10.1007/s12686-016-0591-2>.
33
34 568
35
36 569 Dumilag RV, Gallardo WGM, Garcia CPC, You Y, Chaves AKG, Agahan L. 2018.
37
38 570 Phenotypic and mtDNA variation in Philippine *Kappaphycus cottonii* (Gigartinales,
39
40 571 Rhodophyta). Mitochondrial DNA Part A. 29(6):951–963. doi:
41
42 572 <https://doi.org/10.1080/24701394.2017.1398745>.
43
44 573
45
46 574 Elias M, Penet L, Vindry P, McKey D, Panaud O, Robert T. 2001. Unmanaged sexual
47
48 575 reproduction and the dynamics of genetic diversity of a vegetatively propagated crop
49
50
51
52
53
54
55
56
57
58
59
60

- 1
2
3 576 plant, cassava (*Manihot esculenta* Crantz), in a traditional farming system. Mol
4
5
6 577 Ecol. 10(8):1895–1907. doi: <http://doi.org/10.1046/j.0962-1083.2001.01331.x>.
7
8
9 578
10
11 579 FAO. 2020. The state of world fisheries and aquaculture: sustainability in action.
12
13
14 580 Rome (Italy): FAO. p. 1–206. doi: <https://doi.org/10.4060/ca9229en>.
15
16 581
17
18 582 Fredericq S, Freshwater DW, Hommersand MH. 1999. Observations on the
19
20
21 583 phylogenetic systematics and biogeography of the Solieriaceae (Gigartinales,
22
23 584 Rhodophyta) inferred from *rbcL* sequences and morphological evidence.
24
25
26 585 Hydrobiologia. 398/399:25–38. doi: <https://doi.org/10.1023/A:1017077831840>.
27
28 586
29
30 587 Froehlich HE, Afflerbach JC, Frazier M, Halpern BS. 2019. Blue growth potential to
31
32
33 588 mitigate climate change through seaweed offsetting. *Curr Biol*. 29(18):3087-
34
35
36 589 3093.e3. doi: <https://doi.org/10.1016/j.cub.2019.07.041>.
37
38 590
39
40 591 Fry, HT. 1970. Alexander Dalrymple (1737–1808) and the expansion of British trade.
41
42
43 592 London (United Kingdom): Frank Cass & Co.
44
45 593
46
47 594 Ganzon-Fortes ET, Trono GC, Villanueva RD, Romero JB, Montaña MNE. 2012.
48
49
50 595 'Endong', a rare variety of the farmed carrageenophyte *Eucheuma denticulatum*
51
52
53 596 (Burman) Collins & Hervey from the Philippines. *J Appl Phycol*. 24(5):1107–1111.
54
55 597 doi: <https://doi.org/10.1007/s10811-011-9740-x>.
56
57 598
58
59
60

1
2
3 599 Glenn EP, Doty MS. 1992. Water motion affects the growth rates of *Kappaphycus*
4
5 600 *alvarezii* and related red seaweeds. *Aquaculture*. 108(3–4):233–246. doi:
6
7
8 601 [https://doi.org/10.1016/0044-8486\(92\)90109-X](https://doi.org/10.1016/0044-8486(92)90109-X).
9

10 602
11
12
13 603 Guillemin ML, Faugeton S, Destombe C, Viard F, Correa JA, Valero M. 2008.
14
15 604 Genetic variation in wild and cultivated populations of the haploid–diploid red alga
16
17 605 *Gracilaria chilensis*: how farming practices favor asexual reproduction and
18
19 606 heterozygosity. *Evol* 62(6):1500–1519. doi: <https://doi.org/10.1111/j.1558->
20
21 607 [5646.2008.00373.x](https://doi.org/10.1111/j.1558-5646.2008.00373.x).
22
23
24

25 608
26
27 609 Gurav R, Bhatia SK, Choi T-R, Choi Y-K, Kim HJ, Song H-S, Lee SM, Lee Park S, Lee
28
29 610 HS, Koh J, et al. 2021. Application of macroalgal biomass derived biochar and
30
31 611 bioelectrochemical system with *Shewanella* for the adsorptive removal and
32
33 612 biodegradation of toxic azo dye. *Chemosphere*. 264:128539. doi:
34
35 613 <https://doi.org/10.1016/j.chemosphere.2020.128539>.
36
37
38
39

40 614
41
42 615 Halling C, Wikström SA, Lilliesköld-Sjöo G, Mörk E, Lundsør E, Zuccarello GC. 2013.
43
44 616 Introduction of Asian strains and low genetic variation in farmed seaweeds:
45
46 617 indications for new management practices. *J Appl Phycol*. 25(1):89–95. doi:
47
48 618 <https://doi.org/10.1007/s10811-012-9842-0>.
49
50

51 619
52
53
54 620 Hayashi L, de Paula, EJ, Chow F. 2007. Growth rate and carrageenan analyses in
55
56 621 four strains of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) farmed in the
57
58
59
60

- 1
2
3 622 subtropical waters of São Paulo State, Brazil. J Appl Phycol. 19(5):393–399. doi:
4
5 623 <https://doi.org/10.1007/s10811-006-9135-6>.
6
7
8 624
9
10 625 Hardigan MA, Laimbeer FPE, Newton L, Crisovan E, Hamilton JP, Vaillancourt B,
11
12 626 Wiegert-Rininger K, Wood JC, Douches DS, Farré EM, Veilleux RE, Buell CR. 2017.
13
14
15
16 627 Genome diversity of tuber-bearing *Solanum* uncovers complex evolutionary history
17
18 628 and targets of domestication in the cultivated potato. Proc Nat Acad Sci
19
20 629 114(46):E9999-E10008. Doi: <https://doi.org/10.1073/pnas.1714380114>.
21
22
23 630
24
25 631 Heery EC, Lian KY, Loke LHL, Tan HTW, Todd PA. 2020. Evaluating seaweed farming
26
27 632 as an eco-engineering strategy for 'blue' shoreline infrastructure. Ecol Eng.
28
29 633 152:105857. doi: <https://doi.org/10.1016/j.ecoleng.2020.105857>.
30
31
32 634
33
34 635 Hinaloc LAR, Roleda MY. 2021. Phenotypic diversity, growth and sexual
35
36 636 differentiation in the progeny of wild *Kappaphycus alvarezii* (Gigartinales,
37
38 637 Florideophyceae). Phycologia. doi: <https://doi.org/10.1080/00318884.2021.1946307>.
39
40
41
42 638
43
44
45 639 Hopkins NA. 2006. The place of maize in indigenous Mesoamerican folk taxonomies.
46
47 640 In: Staller JE, Tykot RH, Benz BF, editors. Histories of maize: Multidisciplinary
48
49 641 approaches to the prehistory, linguistics, biogeography, domestication, and evolution
50
51 642 of maize. Burlington (MA): Elsevier/Academic Press. p. 612–622.
52
53
54
55 643
56
57
58
59
60

- 1
2
3 644 Hurtado AQ, Biter AB. Plantlet regeneration of *Kappaphycus alvarezii* var. *adik-adik*
4
5
6 645 by tissue culture. J Appl Phycol. 19(6):783–786. doi:
7
8 646 <https://doi.org/10.1007/s10811-007-9269-1>.
9
10
11 647
12
13 648 Hurtado AQ, Yunque, DA, Tibubos K, Critchley AT. 2009. Use of Acadian marine
14
15 649 plant extract powder from *Ascophyllum nodosum* in tissue culture
16
17
18 650 of *Kappaphycus* varieties. J Appl Phycol. 21(6):633–639. doi:
19
20 651 <https://doi.org/10.1007/s10811-008-9395-4>.
22
23 652
24
25 653 Hurtado AQ, Lim PE, Tan J, Phang SM, Neish IC, Critchley AT. 2016. Biodiversity and
26
27 654 biogeography of commercial tropical carrageenophytes in the Southeast Asian
28
29
30 655 region. In: Pereira L, editor. Carrageenans: Sources and extraction methods,
31
32 656 molecular structure, bioactive properties and health effects. (NY): Nova Science
33
34
35 657 Publishers. p. 51–74.
36
37 658
38
39
40 659 Hurtado AQ, Neish IC, Critchley AT. 2019. Phyconomy: the extensive cultivation of
41
42 660 seaweeds, their sustainability and economic value, with particular reference to
43
44
45 661 important lessons to be learned and transferred from the practice of Eucheumatoid
46
47 662 farming. Phycologia. 58(5):472–483. doi:
48
49 663 <https://doi.org/10.1080/00318884.2019.1625632>.
50
51 664
52
53
54 665 Hussin H, Khoso A. 2021. Migrant workers in the seaweed sector in Sabah, Malaysia.
55
56 666 SAGE Open. July 2021. doi: <https://doi.org/10.1177/21582440211047586>.
57
58
59 667
60

- 1
2
3 668 Jang Y, Shin H, Lee MK, Kwon OS, Shin JS, Kim Y, Kim CW, Lee H, Kim M. 2021.
4
5 669 Antiviral activity of lambda-carrageenan against influenza viruses and severe acute
6
7
8 670 respiratory syndrome coronavirus 2. *Sci Rep* 11:821. doi:
9
10 671 <https://doi.org/10.1038/s41598-020-80896-9>.
11
12
13
14 672
15
16 673 Kelly ELA, Cannon AL, Smith JE. 2020. Environmental impacts and implications of
17
18 674 tropical carrageenophyte seaweed farming. *Conserv Biol.* 34(2):326–337. doi:
19
20 675 <https://doi.org/10.1111/cobi.13462>.
21
22
23 676
24
25 677 Kraft GT. 1997. In memoriam, Maxwell Stanford Doty (1916-1996). *Phycologia.*
26
27 678 36(1):82–90. doi: <https://doi.org/10.2216/i0031-8884-36-1-82.1>.
28
29
30 679
31
32 680 Labeyrie V, Thomas M, Muthamia ZK, Leclerc C. 2016. Seed exchange networks,
33
34 681 ethnicity, and sorghum diversity. *Proc Natl Acad Sci.* 113(1):98–103. doi:
35
36 682 <https://doi.org/10.1073/pnas.1513238112>.
37
38
39 683
40
41 684 Larson S, Stoeckl N, Fachry ME, Dalvi Mustafa M, Lapong I, Purnomo AH, Rimmer
42
43 685 MA, Paul NA. 2021. Women’s well-being and household benefits from seaweed
44
45 686 farming in Indonesia. *Aquaculture.* 530:735711. doi:
46
47 687 <https://doi.org/10.1016/j.aquaculture.2020.735711>.
48
49
50 688
51
52 689 Li Y, Liu N, Wang X, Tang X, Zhang L, Meinita MDN, Wang G, Yin H, Jin Y, Wang H,
53
54 690 et al. 2018. Comparative genomics and systematics of *Betaphycus*, *Eucheuma*, and
55
56
57
58
59
60

- 1
2
3 691 *Kappaphycus* (Solieriaceae: Rhodophyta) based on mitochondrial genome. J Appl
4
5
6 692 Phycol. 30(6):3435–3443. doi: <https://doi.org/10.1007/s10811-018-1450-1>.
7
8 693
9
10 694 Liao LM. 1996. Validation of names transferred to *Kappaphycus* Doty from
11
12 695 *Eucheuma* J. Agardh (Rhodophyta: Solieriaceae). Philipp J Sci. 125:158–160.
13
14 696
15
16
17 697 Lim P-E, Yang L-E, Tan J, Maggs CA, Brodie J. 2017. Advancing the taxonomy of
18
19 698 economically important red seaweeds (Rhodophyta). Eur J Phycol. 52(4):438–451.
20
21 699 doi: <https://doi.org/10.1080/09670262.2017.1365174>.
22
23 700
24
25
26
27 701 Loko YLE, Ewedje E-E, Orobiyi A, Djedatin G, Toffa J, Gbemavo CDSJ, Tchakpa C,
28
29 702 Gavoedo D, Sedah P, Sabot F. 2021. On-farm management of rice diversity, varietal
30
31 703 preference criteria, and farmers' perceptions of the African (*Oryza glaberrima*
32
33 704 Steud.) versus Asian rice (*Oryza sativa* L.) in the Republic of Benin (West Africa):
34
35 705 Implications for breeding and conservation. Econ Bot. 75(1):1–29. doi:
36
37 706 <https://doi.org/10.1007/s12231-021-09515-6>.
38
39
40
41 707
42
43
44 708 Mansa RF, Chen WC, Yeo S, Farm Y, Bakar HA, Sipaut CS. 2013. Fermentation study
45
46 709 on macroalgae *Eucheuma cottonii* for bioethanol production via varying acid
47
48 710 hydrolysis. In: Pogaku R, Sarbatly RH, editors. Advances in biofuels. Boston (MA):
49
50 711 Springer. p. 219–240.
51
52 712
53
54
55 713 Marchi F, Plastino EM. 2020. Codominant inheritance of polymorphic color mutant
56
57 714 and characterization of a bisexual mutant of *Gracilaria caudata* (Gracilariales,
58
59
60

- 1
2
3 715 Rhodophyta). *J Appl Phycol.* 32(6):4385–4398. doi: <https://doi.org/10.1007/s10811->
4
5 716 [020-02199-w](https://doi.org/10.1007/s10811-020-02199-w).
6
7
8 717
9
10 718 Matanjun P, Mohamed S, Mustapha NM, Muhammad K. 2009. Nutrient content of
11
12 719 tropical edible seaweeds, *Euचेuma cottonii*, *Caulerpa lentillifera* and *Sargassum*
13
14 720 *polycystum*. *J Appl Phycol.* 21(1):75–80. doi: <https://doi.org/10.1007/s10811-008->
15
16 721 [9326-4](https://doi.org/10.1007/s10811-008-9326-4).
17
18 722
19
20 723 Mateo JP, Campbell I, Cottier-Cook EJ, Luhan MRJ, Ferriols VMEN, Hurtado AQ.
21
22 724 2021. Understanding biosecurity: knowledge, attitudes and practices of seaweed
23
24 725 farmers in the Philippines. *J Appl Phycol.* 33(2):997–1010. doi:
25
26 726 <https://doi.org/10.1007/s10811-020-02352-5>.
27
28 727
29
30 728 Mattes V. 2014. Types of reduplication: A case study of Bikol. Berlin (Germany): De
31
32 729 Gruyter Mouton.
33
34 730
35
36 731 McKey D, Elias M, Pujol B, Duputié A. 2010. The evolutionary ecology of clonally
37
38 732 propagated domesticated plants. *New Phytol.* 186(2):318–332. doi:
39
40 733 <http://doi.org/10.1016/j.foodchem.2021.130084>.
41
42 734
43
44 735 McKim JM, Willoughby JA, Blakemore WR, Weiner ML. 2019. Clarifying the confusion
45
46 736 between poligeenan, degraded carrageenan, and carrageenan: A review of the
47
48 737 chemistry, nomenclature, and in vivo toxicology by the oral route. *Crit Rev Food Sci*
49
50 738 *Nutr.* 59(19):3054–3073. doi: <https://doi.org/10.1080/10408398.2018.1481822>.
51
52
53
54
55
56
57
58
59
60

- 1
2
3 739
4
5
6 740 Mendoza WG, Montaño NE, Ganzon-Fortes ET, Villanueva R. 2002. Chemical and
7
8 741 gelling profile of ice-ice infected carrageenan from *Kappaphycus striatum* (Schmitz)
9
10 742 Doty "sacol" strain (Solieriaceae, Gigartinales, Rhodophyta). J Appl Phycol. 14(5):
11
12 743 409–418. doi: <https://doi.org/10.1023/A:1022178119120>
13
14
15 744
16
17 745 Meyer RS, DuVal AE, Jensen HR. 2012. Patterns and processes in crop
18
19 746 domestication: an historical review and quantitative analysis of 203 global food
20
21 747 crops. New Phytol. 196(1):29–48. doi: <https://doi.org/10.1111/j.1469->
22
23 748 [8137.2012.04253.x](https://doi.org/10.1111/j.1469-8137.2012.04253.x).
24
25
26
27 749
28
29 750 Morokutti-Kurz M, Fröba M, Graf P, Große M, Grassauer A, Auth J, Schubert U,
30
31 751 Prieschl-Grassauer E. 2021. Iota-carrageenan neutralizes SARS-CoV-2 and inhibits
32
33 752 viral replication in vitro. PLoS ONE. 16(2):e0237480. doi:
34
35 753 <https://doi.org/10.1371/journal.pone.0237480>.
36
37
38
39 754
40
41 755 Msuya FE, Hurtado AQ. 2017. The role of women in seaweed aquaculture in the
42
43 756 Western Indian Ocean and South-East Asia. Eur J Phycol. 52(4):482–494. doi:
44
45 757 <https://doi.org/10.1080/09670262.2017.1357084>.
46
47
48
49 758
50
51 759 Naylor RL, Hardy RW, Buschmann AH, Bush SR, Cao L, Klinger DH, Little DC,
52
53 760 Lubchenco J, Shumway SE, Troell M. 2021. A 20-year retrospective review of global
54
55 761 aquaculture. Nature. 591(7851):551–563. doi: <https://doi.org/10.1038/s41586-021->
56
57 762 [03308-6](https://doi.org/10.1038/s41586-021-03308-6).
58
59
60

1
2
3 763
4
5
6 764 Neish IC, Sepulveda M, Hurtado AQ, Critchley AT. 2017. Reflections on the
7
8 765 commercial development of eucheumatoid seaweed farming. In: Hurtado AQ,
9
10 766 Critchley AT, Neish IC, editors. Tropical seaweed farming trends, problems and
11
12 767 opportunities: focus on *Kappaphycus* and *Eucheuma*. Cham (Switzerland): Springer.
13
14 768 p. 1–27. doi: https://doi.org/10.1007/978-3-319-63498-2_1.

15
16 769
17
18
19
20 770 Nimmo AH. 1986. Recent population movements in the Sulu Archipelago:
21
22 771 Implications to Sama culture history. Archipel. 32:25–38. doi:
23
24 772 10.3406/arch.1986.2307.

25
26 773
27
28
29
30 774 Nor AM, Gray TS, Caldwell GS, Stead SM. 2017. Is a cooperative approach to
31
32 775 seaweed farming effectual? An analysis of the seaweed cluster project (SCP),
33
34 776 Malaysia. J Appl Phycol. 29(5):2323–2337. doi: [https://doi.org/10.1007/s10811-016-](https://doi.org/10.1007/s10811-016-1025-y)
35
36 777 [1025-y](https://doi.org/10.1007/s10811-016-1025-y).

37
38 778
39
40
41
42 779 Norris JN. 2014. Marine algae of the northern Gulf of California II: Rhodophyta.
43
44 780 Smithson Contrib Bot. 96:1–555. doi: <https://doi.org/10.5479/si.19382812.96>.

45
46 781
47
48
49 782 Núñez-Resendiz ML, Dreckmann KM, Senties A, Wynne MJ, León-Tejera HP. 2019.
50
51 783 *Eucheumatopsis isiformis* gen. & comb. nov. (Solieriaceae, Rhodophyta) from the
52
53 784 Yucatan Peninsula, to accommodate *Eucheuma isiforme*. Phycologia. 58(1):51–62.
54
55 785 doi: <https://doi.org/10.1080/00318884.2018.1517536>.

56
57
58
59 786
60

- 1
2
3 787 O'Connor K, Kilian A, Hayes B, Hardner C, Nock C, Baten A, Alam M, Topp B. 2019.
4
5 788 Population structure, genetic diversity and linkage disequilibrium in a macadamia
6
7 789 breeding population using SNP and silicoDArT markers. *Tree Genet Genomes*.
8
9
10 790 15(24): 1–16. doi: <https://doi.org/10.1007/s11295-019-1331-z>.
11
12
13
14 791
15
16 792 Pandey J, Scheuring DC, Koym JW, Coombs J, Novy RG, Thompson AL, Holm DG,
17
18 793 Douches DS, Vales MI. 2021. Genetic diversity and population structure of
19
20 794 advanced clones selected over forty years by a potato breeding program in the
21
22 795 USA. *Sci Rep*. 11(1):1–18. doi: <https://doi.org/10.1038/s41598-021-87284-x>.
23
24
25
26 796
27
28 797 Parenrengi A, Dworjanyn S, Syah R, Pongmasak PR, Fahrur M. 2020. Strain selection
29
30 798 for growth enhancement of wild and cultivated eucheumatoid seaweed species in
31
32 799 Indonesia. *Sains Malays*. 49(10):2453–2464. doi: [https://doi.org/10.17576/jsm-](https://doi.org/10.17576/jsm-2020-4910-11)
33
34 800 [2020-4910-11](https://doi.org/10.17576/jsm-2020-4910-11).
35
36
37
38 801
39
40 802 Parker HS. 1974. The culture of the red algal genus *Eucheuma* in the Philippines.
41
42 803 *Aquac*. 3:425–439. [https://doi.org/10.1016/0044-8486\(74\)90009-X](https://doi.org/10.1016/0044-8486(74)90009-X).
43
44
45 804
46
47 805 Pautasso M, Aistara G, Barnaud A, Caillon S, Clouvel P, Coomes OT, Delêtre M,
48
49 806 Demeulenaere E, De Santis P, Döring T, et al. 2012. Seed exchange networks for
50
51 807 agrobiodiversity conservation. A review. *Agron Sustain Dev*. 33(1):151–175. doi:
52
53 808 <https://doi.org/10.1007/s13593-012-0089-6>.
54
55
56
57 809
58
59
60

- 1
2
3 810 Pereira L, Critchley AT. 2020. The COVID 19 novel coronavirus pandemic 2020:
4
5 811 seaweeds to the rescue? Why does substantial, supporting research about the
6
7 812 antiviral properties of seaweed polysaccharides seem to go unrecognized by the
8
9 813 pharmaceutical community in these desperate times? J Appl Phycol. 32(3):1875–
10
11 814 1877. doi: <https://doi.org/10.1007/s10811-020-02143-y>.
12
13
14
15 815
16
17 816 Periyasamy C, Anantharaman P, Balasubramanian T. 2014. Social upliftment of
18
19 817 coastal fisher women through seaweed (*Kappaphycus alvarezii* (Doty) Doty) farming
20
21 818 in Tamil Nadu, India. J Appl Phycol. 26(2):775–781. doi:
22
23 819 <https://doi.org/10.1007/s10811-013-0228-8>.
24
25
26
27 820
28
29 821 Phang S-M, Yeong H-Y, Lim P-E, Nor ARM, Gan KT. 2010. Commercial varieties of
30
31 822 *Kappaphycus* and *Euचेuma* in Malaysia. Malays J Sci. 29(3):214–224. doi:
32
33 823 <https://doi.org/10.22452/mjs.vol29no3.4>.
34
35
36
37 824
38
39 825 Plastino EM, Guimarães M, Matioli SR, Oliveira EC. 1999. Codominant inheritance of
40
41 826 polymorphic color variants of *Gracilaria domingensis* (Gracilariales, Rhodophyta).
42
43 827 Genet Mol Biol. 22(1):105–108. doi: <https://doi.org/10.1590/S1415->
44
45 828 [47571999000100020](https://doi.org/10.1590/S1415-47571999000100020).
46
47
48
49 829
50
51 830 Purbosari N, Warsiki E, Syamsu K, Santoso J, Effendi I. 2021. Evaluation of the
52
53 831 application of seaweed (*Euचेuma cottonii*) extract as fish anesthetic agent. Aquac
54
55 832 Int [Internet]. [accessed 2021 Aug 5]. doi: <https://doi.org/10.1007/s10499-021->
56
57 833 [00693-7](https://doi.org/10.1007/s10499-021-00693-7).
58
59
60

1
2
3 834

4
5 835 Quiaoit HAR, Uy WH, Bacaltos DGG, Chio PBR. 2016. Seaweed area GIS-based
6
7
8 836 mapping. Production support system for sustainable seaweed farming in the
9
10 837 Philippines 2016 report. Cagayan de Oro (Philippines): Xavier University Press.

11
12
13 838

14
15 839 Ramu P, Esuma W, Kawuki R, Rabbi IY, Egesi C, Bredeson JV, Bart RS, Verma J,
16
17 840 Buckler ES, Lu, F. 2017. Cassava haplotype map highlights fixation of deleterious
18
19 841 mutations during clonal propagation. Nat Genet 49(6): 959–963. doi:

20
21
22 842 <https://doi.org/10.1038/ng.3845>.

23
24
25 843

26
27 844 Risjani Y, Abidin G. 2020. Genetic diversity and similarity between green and brown
28
29 845 morphotypes of *Kappaphycus alvarezii* using RAPD. J Appl Phycol. 32(4):2253–2260.
30
31 846 doi: <https://doi.org/10.1007/s10811-020-02223-z>.

32
33
34 847

35
36
37 848 Roleda MY, Heesch S. 2021. Chemical profiling of *Ulva* species for food applications:
38
39 849 What is in a name? Food Chem. 361:130084. doi:
40
41 850 <https://doi.org/10.1016/j.foodchem.2021.130084>.

42
43
44
45 851

46
47 852 Roleda MY, Hurd CL. 2019. Seaweed nutrient physiology: Application of concepts to
48
49 853 aquaculture and bioremediation. Phycologia. 58(5):552–562. doi:
50
51 854 <https://doi.org/10.1080/00318884.2019.1622920>.

52
53
54
55 855
56
57
58
59
60

- 1
2
3 856 Roleda MY, Aguinaldo Z-ZA, Crisostomo BA, Hinaloc LAR, Projimo VZ, Dumilag RV,
4
5
6 857 Lluisma AO. 2021a. Discovery of novel haplotypes from wild populations of
7
8 858 *Kappaphycus* (Gigartinales, Rhodophyta) in the Philippines. *Algae*. 36(1):1–12. doi:
9
10 859 <https://doi.org/10.4490/algae.2021.36.2.18>.
11
12
13 860
14
15 861 Roleda MY, Lage S, Aluwini DF, Rebours C, Brurberg MB, Nitschke U, Gentili FG.
16
17 862 2021b. Chemical profiling of the Arctic sea lettuce *Ulva lactuca* (Chlorophyta) mass-
18
19 863 cultivated on land under controlled conditions for food applications. *Food Chem*.
20
21 864 341:127999. doi: <https://doi.org/10.1016/j.foodchem.2020.127999>.
22
23
24
25 865
26
27 866 Roleda MY, Lage S, Aluwini DF, Rebours C, Brurberg MB, Nitschke U, Gentili FG.
28
29 867 2021c. Corrigendum to "Chemical profiling of the Arctic sea lettuce *Ulva lactuca*
30
31 868 (Chlorophyta) mass-cultivated on land under controlled conditions for food
32
33 869 applications" [*Food Chemistry*, 341 (2021) 127999]. *Food Chem*. 347:129059. doi:
34
35 870 <https://doi.org/10.1016/j.foodchem.2021.129059>.
36
37
38
39
40 871
41
42 872 Rubino C. 2005. Reduplication: form, function and distribution. In: Hurch B, Mattes
43
44 873 V, editors. *Studies on reduplication*. Berlin (Germany): Mouton de Gruyter.
45
46
47 874
48
49 875 Saleeby NM. 1908. *The History of Sulu*. Manila (Philippines): Bureau of Printing.
50
51
52 876
53
54 877 Santiañez WJE, Wynne MJ. 2020. Establishment of *Mimica* gen. nov. to
55
56 878 accommodate the anaxiferous species of the economically important red seaweed
57
58
59
60

- 1
2
3 879 *Eucheuma* (Solieriaceae, Rhodophyta). Phytotaxa. 439(2):167–170. doi:
4
5 880 <https://doi.org/10.11646/phytotaxa.439.2.8>.
6
7
8 881
9
10 882 Schmidtchen L, Roleda MY, Majschak JP, Mayser M. 2021. Processing technologies
11
12 883 for solid and flexible packaging materials from macroalgae. Algal Res. 102300. doi:
13
14 884 <https://doi.org/10.1016/j.algal.2021.102300>.
15
16 885
17
18 886 Smýkal P, Nelson M, Berger J, Von Wettberg E. 2018. The impact of genetic changes
19
20 887 during crop domestication. Agronomy. 8(7):119. doi:
21
22 888 <https://doi.org/10.3390/agronomy8070119>.
23
24 889
25
26 890 Surya I, Chong EWN, Abdul Khalil HPS, Funmilayo OG, Abdullah CK, Sri Aprilia NA,
27
28 891 Olaiya NG, Lai TK, Oyekanmi AA. 2021. Augmentation of physico-mechanical,
29
30 892 thermal and biodegradability performances of bio-precipitated material reinforced in
31
32 893 *Eucheuma cottonii* biopolymer films. J Mater Res Technol. 12:1673–1688. doi:
33
34 894 <https://doi.org/10.1016/j.jmrt.2021.03.055>.
35
36 895
37
38 896 Suyo JGB, Le Masson V, Shaxson L, Luhan MRJ, Hurtado AQ. 2021. Navigating risks
39
40 897 and uncertainties: Risk perceptions and risk management strategies in the Philippine
41
42 898 seaweed industry. Mar Policy. 126:104408. doi:
43
44 899 <https://doi.org/10.1016/j.marpol.2021.104408>.
45
46 900
47
48 901
49
50
51
52
53
54
55
56
57
58
59
60

- 1
2
3 902 Tan, J., Lim, P.-E., Phang, S.-M., Hong, D.D., Sunarpi, H., & Hurtado, A.Q. (2012)
4
5 903 Assessment of four molecular markers as potential DNA barcodes for red algae
6
7 904 *Kappaphycus Doty* and *Eucheuma J. Agardh* (Solieriaceae, Rhodophyta). PLoS One
8
9 905 7(12):e52905. doi: <http://dx.doi.org/10.1371/journal.pone.0052905>.
10
11
12
13 906
14
15 907 Tan J, Lim PE, Phang SM, Rahiman A, Nikmatullah A, Sunarpi H, Hurtado AQ. 2014.
16
17 908 *Kappaphycus malesianus* sp. nov.: a new species of *Kappaphycus* (Gigartinales,
18
19 909 Rhodophyta) from Southeast Asia. J Appl Phycol. 26(2):1273–1285. doi:
20
21
22 910 <https://doi.org/10.1007/s10811-013-0155-8>.
23
24
25 911
26
27 912 Tano SA, Halling C, Lind E, Buriyo A, Wikström SA. 2015. Extensive spread of farmed
28
29 913 seaweeds causes a shift from native to non-native haplotypes in natural seaweed
30
31 914 beds. Mar Biol. 162(10):1983–1992. doi: [https://doi.org/10.1007/s00227-015-2724-](https://doi.org/10.1007/s00227-015-2724-7)
32
33 915 [7](https://doi.org/10.1007/s00227-015-2724-7).
34
35
36
37 916
38
39 917 Teo BSX, Gan RY, Abdul Aziz S, Sirirak T, Mohd Asmani MF, Yusuf E. 2021. In vitro
40
41 918 evaluation of antioxidant and antibacterial activities of *Eucheuma cottonii* extract and
42
43 919 its in vivo evaluation of the wound-healing activity in mice. J Cosmet Dermatol.
44
45 920 20(3):993–1001. doi: <https://doi.org/10.1111/jocd.13624>.
46
47
48
49 921
50
51 922 Thien VY, Yong WTL, Anton A, Chin GJWL. 2020. A multiplex PCR method for rapid
52
53 923 identification of commercially important seaweeds *Kappaphycus alvarezii*,
54
55 924 *Kappaphycus striatus* and *Eucheuma denticulatum* (Rhodophyta, Solieriaceae). Reg
56
57 925 Stud Mar Sci. 40:101499. doi: <https://doi.org/10.1016/j.rsma.2020.101499>.
58
59
60

- 1
2
3 926
4
5
6 927 Trono GC, Largo DB. 2019. The seaweed resources of the Philippines. *Bot Mar*.
7
8 928 62(5):483–498. doi: <https://doi.org/10.1515/bot-2018-0069>.
9
10 929
11
12
13 930 Trono GC, Lluisma AO, Montaña MNE. 2000. Primer on farming and strain selection
14
15 931 of *Kappaphycus* and *Eucheuma* in the Philippines. Quezon City (Philippines):
16
17 932 PCAMRD, UPMSI and UNDP.
18
19
20 933
21
22
23 934 Turland NJ, Wiersema JH, Barrie FR, Greuter W, Hawksworth DL, Herendeen PS,
24
25 935 Knapp S, Kusber W-H, Li D-Z, Marhold K, et al. 2018. International code of
26
27 936 nomenclature for algae, fungi, and plants (Shenzhen Code) adopted by the
28
29 937 Nineteenth International Botanical Congress Shenzhen, China, July 2017. *Regnum*
30
31 938 *Vegetabile* 159. Glashütten (Germany): Koeltz Botanical Books. doi:
32
33 939 <https://doi.org/10.12705/Code.2018>.
34
35
36
37 940
38
39 941 Usandizaga S, Valenzuela P, Gaitán-Espitia JD, Destombe C, Guillemín ML. 2021.
40
41 942 Reproductive effort in the domesticated red alga *Agarophyton chilense*: differences
42
43 943 between farms and natural populations. *J Appl Phycol*. 33(2):1149–1156.
44
45 944 <https://doi.org/10.1007/s10811-020-02325-8>.
46
47
48
49 945
50
51 946 Valderrama D, Cai J, Hishamunda N, Ridler N, editors. 2013. Social and economic
52
53 947 dimensions of carrageenan seaweed farming. Rome (Italy): FAO. Fisheries and
54
55 948 aquaculture technical paper no. 580. [accessed 2021 Aug 08].
56
57
58
59
60

- 1
2
3 949 <http://www.fao.org/3/i3344e/i3344e.pdf>. Food and Agriculture Organization of the
4
5 950 United Nations.
6
7
8 951
9
10 952 Valero M, Guillemain M-L, Destombe C, Jacquemin B, Gachon CMM, Badis Y,
11
12 953 Buschmann AH, Camus C, Faugeron S. 2017. Perspectives on domestication
13
14 954 research for sustainable seaweed aquaculture. *Perspect Phycol.* 4(1):33–46. doi:
15
16 955 <https://doi.org/10.1127/pip/2017/0066>.
17
18 956
19
20 957 van der Meer JP. 1979. Genetics of *Gracilaria tikvahiae* (Rhodophyceae). VI.
21
22 958 Complementation and linkage analysis of pigmentation mutants. *Can J Bot.*
23
24 959 57(1):64–68. doi: <https://doi.org/10.1139/b79-013>.
25
26 960
27
28 961 Velasquez GT. 1977. History on the local uses of seaweeds. *Sci Rev.* 18:20–24.
29
30 962
31
32 963 Villanueva RD, Mendoza WG, Rodriguez MRC, Romero JB, Montañó MNE. 2004.
33
34 964 Structure and functional performance of gigartinacean kappa–iota hybrid
35
36 965 carrageenan and solieriacean kappa–iota carrageenan blends. *Food Hydrocoll.*
37
38 966 18(2):283–292. doi: [https://doi.org/10.1016/S0268-005X\(03\)00084-5](https://doi.org/10.1016/S0268-005X(03)00084-5).
39
40 967
41
42 968 Wang Y, Wang Y, Sun X, Caiji Z, Yang J, Cui D, Cao G, Ma X, Han B, Xue D, Han L.
43
44 969 2016. Influence of ethnic traditional cultures on genetic diversity of rice landraces
45
46 970 under on-farm conservation in southwest China. *J Ethnobiol Ethnomedicine.*
47
48 971 12(1):51. doi: <https://doi.org/10.1186/s13002-016-0120-0>.
49
50 972
51
52
53
54
55
56
57
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1
2
3 973 Ward GM, Faisan JP, Cottier-Cook EJ, Gachon C, Hurtado AQ, Lim PE, Matoju I,
4
5 974 Msuya FE, Bass D, Brodie J. 2020. A review of reported seaweed diseases and pests
6
7
8 975 in aquaculture in Asia. J World Aquac Soc. 51(4):815–828. doi:
9
10 976 <https://doi.org/10.1111/jwas.12649>.

11
12
13 977

14
15 978 Ward GM, Kambey CSB, Faisan JP, Tan PL, Daumic CC, Matoju I, Stentiford GD, Bass
16
17 979 D, Lim PE, Brodie J, Poong SW. 2021. Ice-ice disease: an environmentally and
18
19 980 microbiologically driven syndrome in tropical seaweed aquaculture. Rev Aquac
20
21 981 <https://doi.org/10.1111/raq.12606>.

22
23
24
25 982

26
27 983 Xiao X, Agustí S, Yu Y, Huang Y, Chen W, Hu J, Li C, Li K, Wei F, Lu Y, et al. 2021.
28
29 984 Seaweed farms provide refugia from ocean acidification. Sci Total Environ.
30
31 985 776:145192. doi: <https://doi.org/10.1016/j.scitotenv.2021.145192>.

32
33
34
35 986

36
37 987 Zheng Y, Jin R, Zhang X, Wang Q, Wu J. 2019. The considerable environmental
38
39 988 benefits of seaweed aquaculture in China. Stoch Environ Res Risk Assess. 33(4–
40
41 989 6):1203–1221. doi: <https://doi.org/10.1007/s00477-019-01685-z>.

42
43
44
45 990

46
47 991 Zuccarello GC, Critchley AT, Smith J, Sieber V, Lhonneur GB, West JA. 2006.
48
49 992 Systematics and genetic variation in commercial *Kappaphycus* and *Eucheuma*
50
51 993 (Solieriaceae, Rhodophyta). J Appl Phycol. 18(3–5):643–651. doi:
52
53 994 <https://doi.org/10.1007/s10811-006-9066-2>.

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Table 1

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

Non-domesticated eucheumatoid species producing ¹iota- or ²kappa-carrageenan.

Table 2.

Local Name (variant)	Etymology (dialect)	cox23 haplotype	Philippine distribution
<i>E. denticulatum</i>			
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 colour		45 ^b , 48 ^b , 47 ^b
Zamboanga	the province of its origin, Zamboanga		54 ^b
<i>K. alvarezii</i>			
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 colour, 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 <i>Kappaphycus cottonii</i> – katunay is an onomatopoeic 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

1	Jackpot, Swerte	Lucky (English, Spanish)		58 ^b
2	Kab-Kab, Pay-Pay	fan-like (Tausug)	3 ^d	35 ^b , 37 ^d , 58 ^b
3	Kinangkong, Natural, Plastic	water spinach-like, vegetable-like (Tagalog)		13 ^b , 14 ^b
4	Kinse-Kinse	refers to fifteen days before harvest (Spanish 'quince')		11 ^b , 12 ^b , 58 ^c
5	Kulot	curly (Tagalog)		37 ^b , 58 ^c
6	Lakway	from 'lakaw' means to walk (Bisaya)		43 ^b , 44 ^b , 54 ^b
7	Marimar	a famous 1990s Mexican soap opera released in the Philippines under the same title	3 ^h	58 ^h
8	Milo-Milo, Milo	a popular brand of cocoa drink, referring to its branch colour	3 ⁱ	35 ^b , 37 ⁱ , 58 ^b
9	Patig	from 'fatigue', a khaki-olive green military suit		58 ^c
10	Pula-Pula	red (Tagalog, Bisaya)		58 ^c
11	Putan	from the same name of a Sama local sticky rice cake. Its brown colour matches that of the cultivar's branches (Tausug)		58 ^c
12	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}
13	Tungawan	a municipality in Zamboanga Sibugay		22 ^j
14	Spinosum (br, gr)	spinous morphology	3 ^h	54 ^h
15	Sweet Loving	unknown etymology		58 ^b
16	Sacol (rd, vanguard)	an island in Zamboanga City	3 ^d	12 ^c , 37 ^d
17	Vanguard	from the brand name of the machine, Vanguard, bought by a seaweed farmer after his good harvest.	3 ^d	37 ^d
18	Way-Way	unknown entity		39 ^b , 41 ^b , 36 ^b ,
19	<i>K. malesianus</i>			
20	Aring-Aring	from Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi		58 ^b
21	Halaw	illegal Filipino deportees to borders of Malaysia (Tausug/Sama)	MY216 ^h	58 ^h
22	Kuku Belleh'	eagle's talon (Sama)	MY216 ^h	58 ^h

<i>K. striatus</i>			
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 <i>Kappaphycus cottonii</i>	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 onomatopoeic 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 Colours	pertains to the seven colours 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
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	<i>Dugong dugon</i> , the sirenian		43 ^b , 44 ^b

1	Duralex	a popular brand name of dishware	35 ^b
2	Durian	from <i>Durio zibethinus</i> , the strongly aromatic fruit in SE Asia	58 ^{b,c}
3			
4	Marlin	a fish belonging to family Istiophoridae	37 ^k
5	Original	originally sourced from Antique province only	19 ^b
6	Polotan	any food eaten without rice (Tagalog)	35 ^b
7	Sakot	ingredient (Bisaya)	19 ^b
8	Sparkle	pertaining to its green colour	58 ^c
9	Sprite	a popular soft drink brand, inspired by the similar green colour of its bottle	12 ^b
10	Tangtang-utang	literally dropping of debt (Bisaya)	37 ^c
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bold numbers indicate site of collection of DNA barcoded specimen/s

bl: black, br: brown, gr: green, gy: grey, or: orange, pu: purple, rd: red

^aGanzon-Fortes et al. 2012

^bQuiaoit et al. 2016

^cThis study

^dLim et al. 2014

^eHurtado and Biter 2007

^fHurtado et al. 2009

^gDumilag and Lluisma 2016

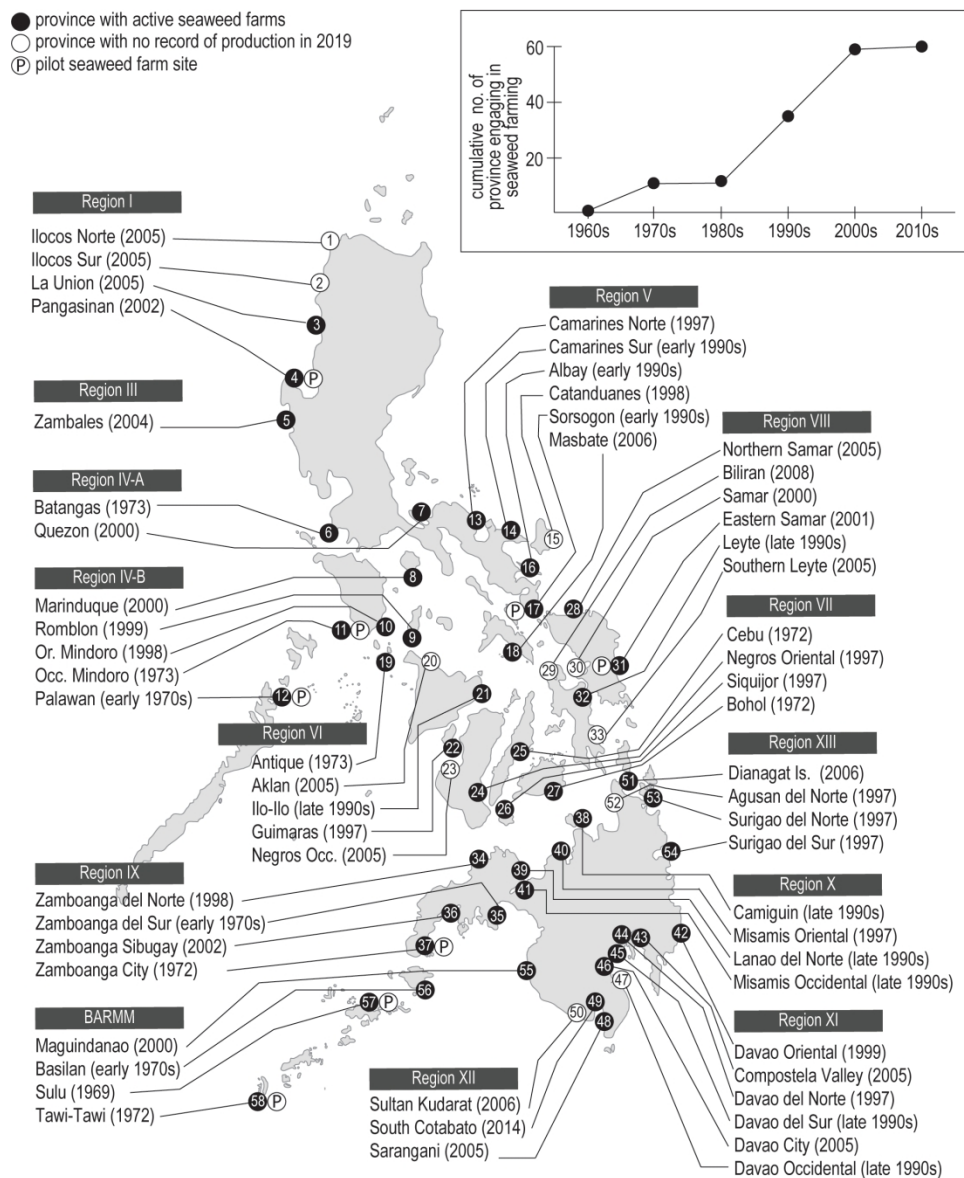
^hDumilag et al. 2016

ⁱTan et al. 2012

^kBorlongan et al. 2011

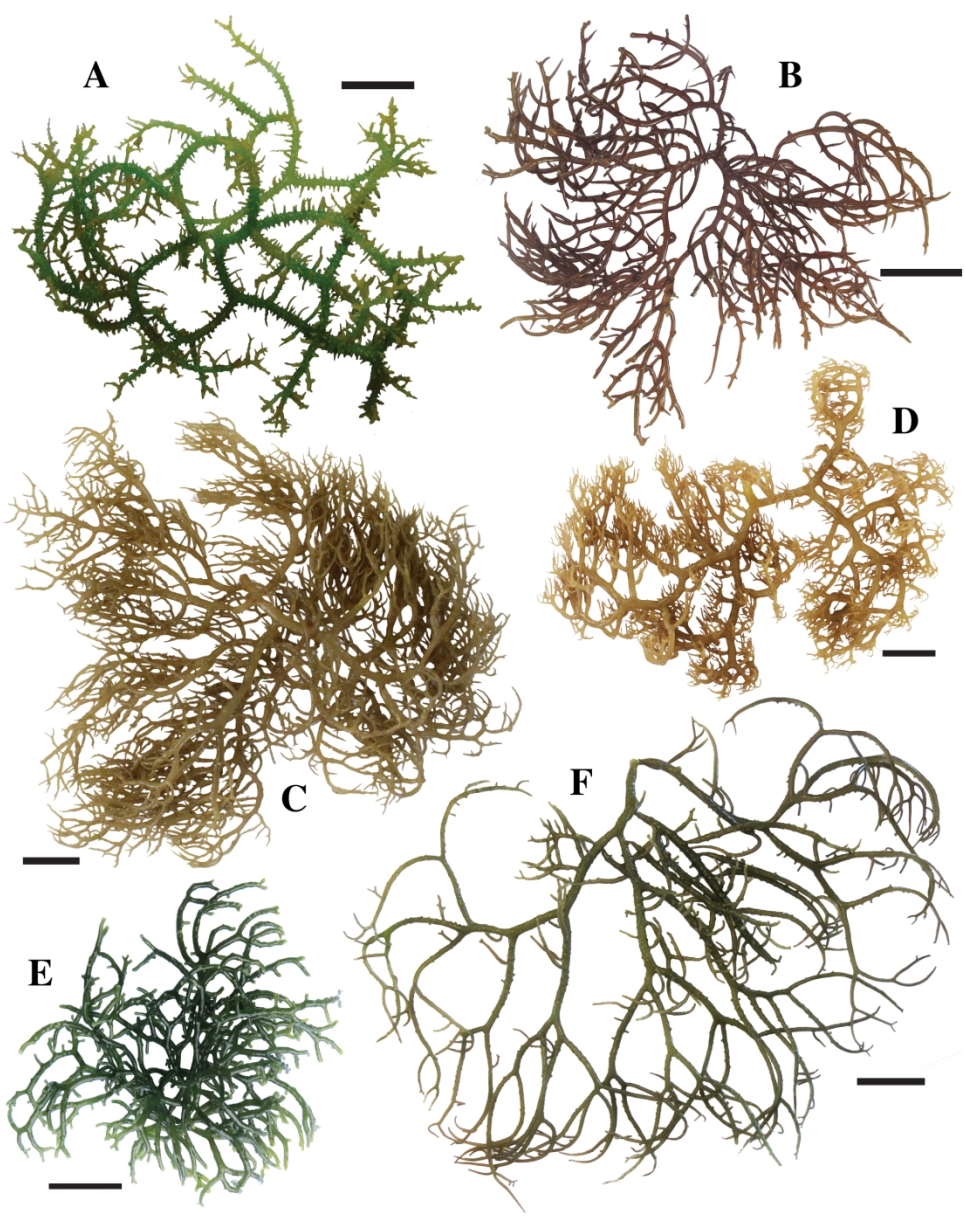
^kSuyo et al. 2020

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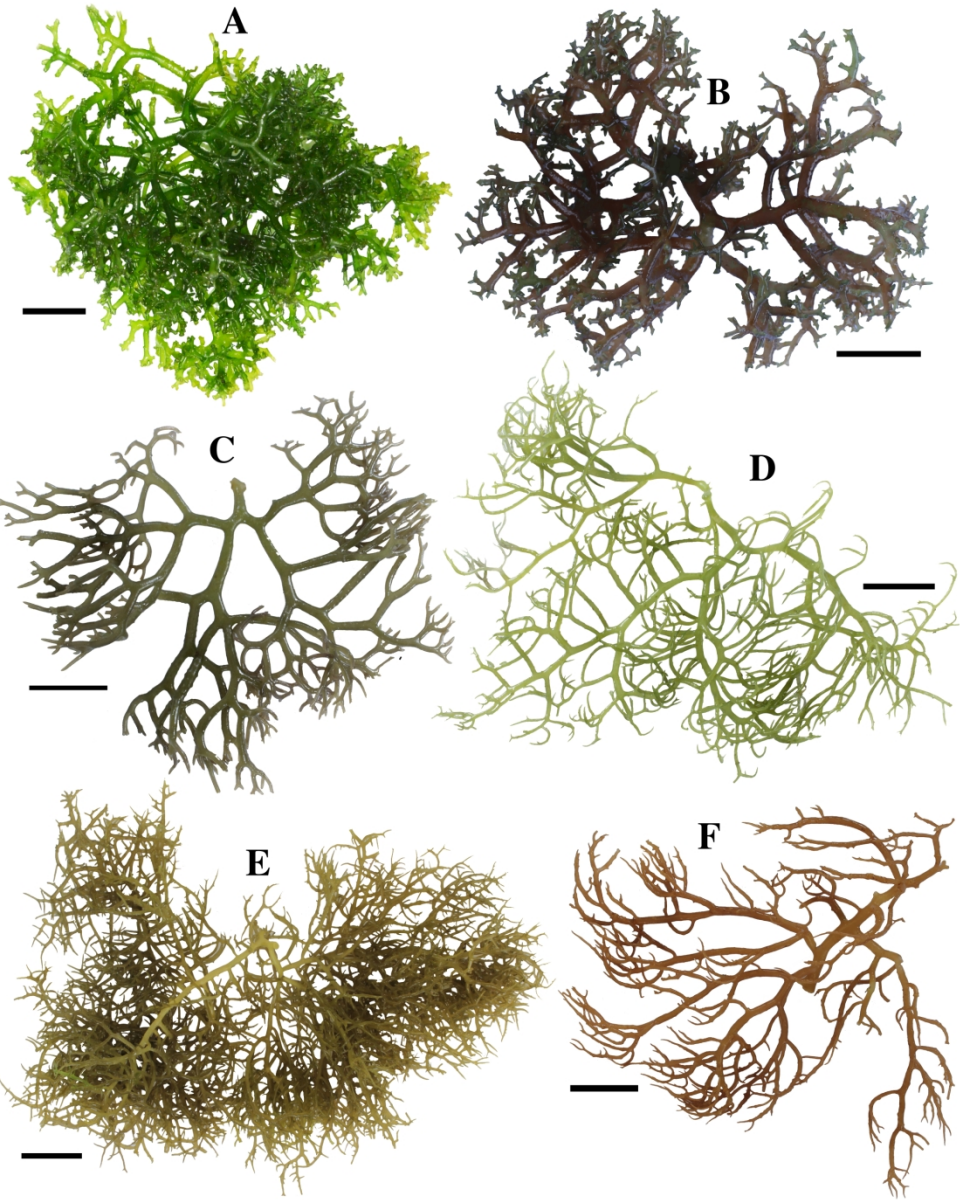


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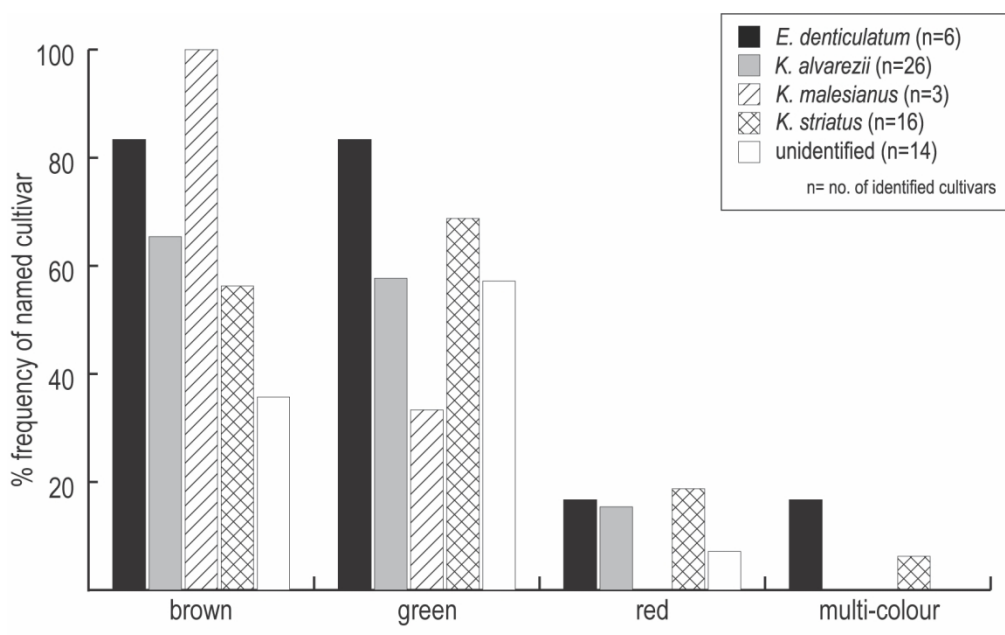
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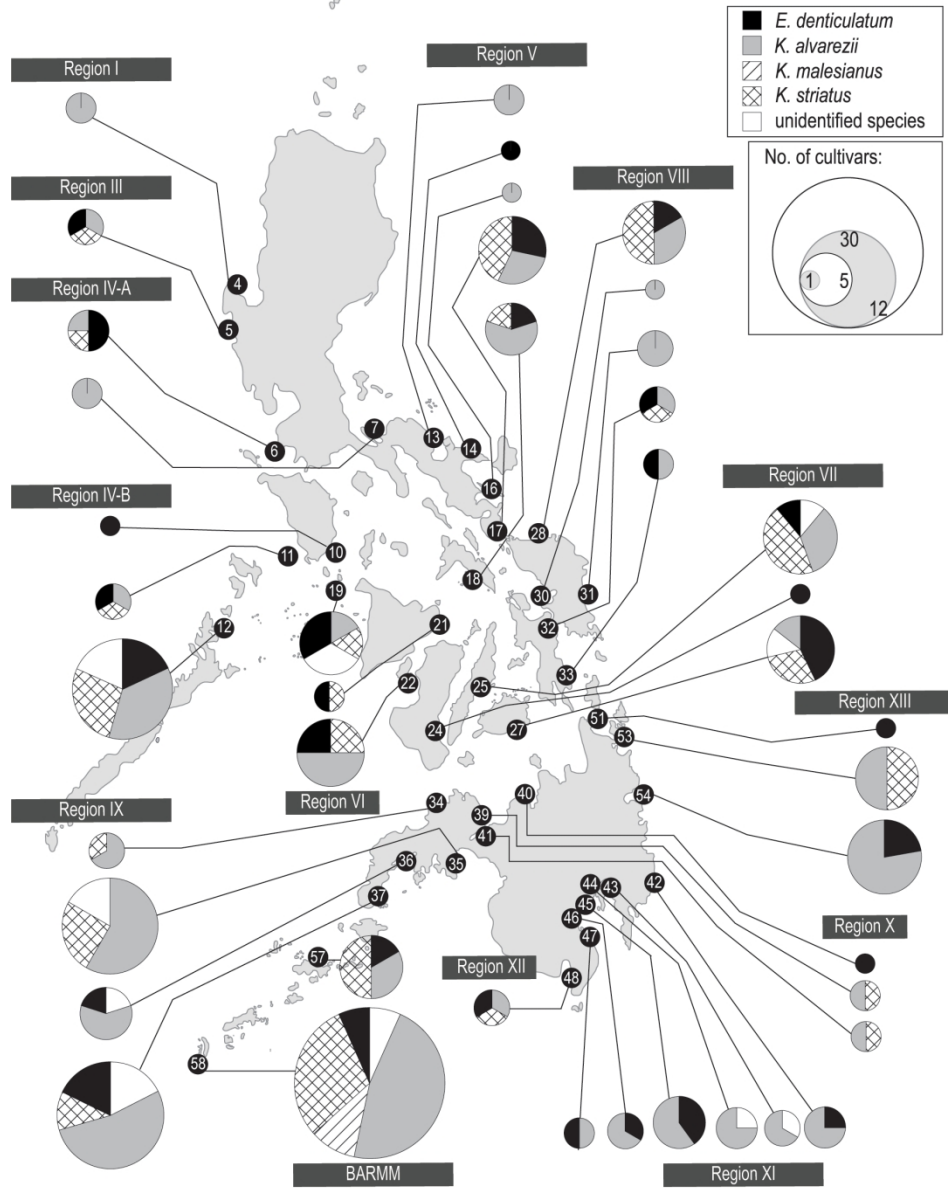


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