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Commercial varieties of *Kappaphycus* and *Eucheuma* in Malaysia

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ABSTRACT The seaweed industry has been identified for priority development in Malaysia. The seaweeds commercially farmed for carrageenan belong to the genera *Kappaphycus* Doty and *Eucheuma* J. Agardh. At least six varieties of *Kappaphycus* and *Eucheuma* are found in the farms around Sabah, east Malaysia. These seaweeds produce carrageenan with gel strength ranging from 250 to 550 $g.cm^{-2}$. This paper provides a simple description of gross morphological features and illustrations that may be used in the field for differentiating the main seaweed varieties cultivated in Sabah.

ABSTRAK Industri rumpair laut telah dikenalpastikan sebagai keutamaan untuk dibangunkan di Malaysia. Rumpair laut yang dikultur secara komersial untuk penghasilan karageenan adalah daripada genera *Kappaphycus* Doty dan *Eucheuma* J. Agardh. Lebih kurang enam jenis *Kappaphycus* dan *Eucheuma* ditemui dari ladang di Sabah, Malaysia Timur. Rumpair laut ini menghasilkan karageenan yang mempunyai kekuatan gel daripada 250 sehingga 550 $g.cm^{-2}$. Kertas ini memberikan gambarajah ringkas terhadap ciri-ciri morfologi kasar beserta ilustrasi yang boleh digunakan di lapangan untuk membezakan jenis-jenis rumpair laut utama yang dikultur di Sabah.

(**Keywords**: *Kappaphycus*, *Eucheuma*, carrageenan, gel strength, seaweed farms,)

INTRODUCTION

The seaweed farming areas of East Malaysia contributes to the high global production of carrageenan by the Coral Triangle (Figure 1). The Coral Triangle is bordered by six nations. In 2007, the global production of carrageenophytic seaweeds (*Kappaphycus* and *Eucheuma*) was more than 200,000 metric tonnes (MT) DW [1], which sold for between USD800 to 1200 per MT DW. The global demand for raw carrageenophytes is projected to reach 400,000 MT DW by 2012, with the Coral Triangle countries contributing 71% of the global production.

In 2009, the total production of *Kappaphycus* within the Coral Triangle was 200,000 MT, and the production by country is as follows: Indonesia (54%); Philippines (40%); Malaysia (3%), Solomon Islands (1%); and Timor Leste (1%). Papaua New Guinea has just started trial plots in the Alatau area in August 2010. The populations within the Coral Triangle are also amongst the poorest in the region, and seaweed farming is an important avenue for poverty eradication.

Seaweed farming is one of three priority development areas for the agriculture sector in Malaysia. The targeted production of the carrageenophytes in Sabah for 2010 is 125,000 MT FW [2]. With about 9,000 ha of farms operated by 1200 families (Figure 2), around Semporna, the 2009 production was 6,000 MT at 40% moisture content. The farms are located in Semporna, Lahad Datu, Kunak, Banggi and Kudat [2]. The seaweeds commercially farmed for carrageenan belong to the genera *Kappaphycus* Doty and *Eucheuma* J. Agardh.

TAXONOMY OF *EUCHEUMA*

The domestication of *Eucheuma* took place in 1973 in the Philippines [3] with the common names of *cottonii*, *spinosum* or *gelatinae* used by the industry. As commercial interest in these carrageenophytes increased, it became important to have proper taxonomy and nomenclature of this genus. *Eucheuma* was established by J.G. Agardh [4] and *Eucheuma denticulatum* (Burman) Colins et Hervey is accepted as the type for the genus. *Eucheuma* identification was based on the presence of three types of tissues in the rigid thallus: (i) rhizoidal medullary core, (ii) rotund medullary cells, (iii) cortex comprising radiating filaments of small, elongated cells [5]. Doty and Norris (1985) [6] provided a practical key to 15 *Eucheuma* species that were major sources of carrageenan. Different species of *Eucheuma* produce different carrageenans (described as alpha, beta, gamma, iota, lambda, kappa, mu and nu) [5]. Using this characteristic and the type of central medullary core (rhizoidal or hyphal), Doty and Norris [6]

rearranged the commercial species into four sections:

(i) *E.* sect. *Eucheuma* [Type: *Eucheuma denticulatum* (Burman) Collins et Hervey]
(ii) *E.* sect. *Anaxiferae* Weber-van Bosse, emend. (Type: *Eucheuma arnoldii* Weber-van Bosse)
(iii) *E.* sect. *Gelatiformia* [Type: *Eucheuma gelatinae* (Esper) J. Agardh]
(iv) *E.* sect. *Cottoniformia* (Type: *Eucheuma alvarezii* Doty)

The *Eucheuma* sect. *Eucheuma* (synonym *Eucheuma* sect. *Axiferae* Weber-van Bosse is distinguished by an axial core of rhizoids, and includes *E. denticulatum* (Burman) Collins et Hervey], *E. spinosum* (Linnaeus) J. Agardh, which produce iota carrageenan. These species are commonly referred to as "spinosum" by the industry.

The *Eucheuma* sect. *Anaxiferae* has whorls of spines on indeterminate and determinate branches, absence of axial hypha and produce iota-carrageenan.

The *Eucheuma.* sect. *Gelatiformia* is distinguished by strap-like segments with compressed axial core of hyphae and the production of kappa-carrageenan.

The *Eucheuma* sect. *Cottoniformia* is characterised by a core of irregular, thin-walled axial hyphae and the production of kappa-carrageenan. *E. alvarezii* and *E. striatum* are included this section and are commercially grouped into the "cottonii" although the *E. cottonii* Weber-van Bosse is not included in this section. Secondary branches are abundant in *E. striatum* but usually absent in *E. alvarezii*.

SEPARATION OF *KAPPAPHYCUS* FROM *EUCHEUMA*

In 1988, Doty revised the four sections of *Eucheuma* by Doty and Norris (1985) [6] by recognising a new tribe *Eucheumatoideae* (type genus: *Eucheuma* J. Agardh) and a new genus *Kappaphycus* (type species: *E. alvarezii* Doty). This tribe comprises *Eucheuma* with three sections (*E.* sect. *Eucheuma*; *E.* sect. *Anaxiferae*; and *E. Gelatiformia*) and *Kappaphycus*. *Kappaphycus* is distinguished from the rest by absence of whorls of spines, rarely with opposite branching, cystocarps on main axes, and the production of kappa-carrageenan. In cross-section, the thallus comprises an inner and outer cortex; the outer cortical cells are radially elongated and pigmented; the inner cortical cells are also radially elongated and thick-walled. The cells get bigger towards the inside to form the medulla. The medullary cells are isodiametric and form a pseudoparenchymatous tissue, with a central core (especially evident at the tips) of filaments forming an axial hypha (Figures 3, 4). In rarely found fertile thalli, cystocarps may be found scattered over the surface of the thallus (Figure 5).

Kappaphycus comprises the following species:

(i) *K. alvarezii* (Doty) Doty (Basionym: *E. alvarezii* Doty); collected from Karindingan Island on Creagh Reef, near Semporna
(ii) *K. inerme* (Smitz) Doty (Basionym: *E. inerme* Schmitz); from Tanzania
(iii) *K. striatum* (Smitz) Doty (Basionym: *E. striata* Smitz) or commonly as *E. striatum*; from Zanzibar, east Africa, Indonesia, eastern Sabah, Philippines
(iv) *K. procrusteanum* (Kraft) Doty (Basionym: *E. procrustanum* Kraft); central Philippines
(v) *K. cottonii* (Weber-van Bosse) Doty (Basionym: *E. cottonii* Weber-van Bosse; Tanzania, Hainan Island, Philippines, Guam, Mauritius.

Eucheuma, distinguished by indeterminate growth with spine-like determinate lateral branches comprises:

(i) *E. denticulatum* (N.L. Burman) Collins et Hervey, from Mozambique, Indonesia, Sabah, Philippines, New Caledonia
(ii) *E. serra* (J. Agardh); Mauritius
(iii) *E. isiforme* (C.Agardh) J. Agardh; Caribbean
(iv) *E. uncinatum* Setchell et Gardner; Gulf of California, Mexico
(v) *E. arnoldii* Weber-van Bosse; Queensland, Ryukus, Taiwan
(vi) *E. amakusaensis* Okamura; Japan, Taiwan, Philippnes
(vii) *E. gelatinae* (esper) J. Agaedh; Philippines, south China
(viii) *E. perplexum* Doty; Taiwan
(ix) *E. kraftianum* Doty; central Indonesia
(x) *E. speciosum* (Sonder) J. Agaardh; western Australiua
(xi) *E. odontophorum* Boergesen; Mauritius, east Africa
(xii) *E. platycladum* Schmitz; east Africa.

Three main varieties of *K. alvarezii* (*E. alvarezii*) recognized are *K. alvarezii* var. *alvarezii* with simple, small, open thallus; *K. alvarezii* var. *tambalang* with bushy thallus comprising smaller indeterminate axes and short segments; *K. alvarezii*

var. *ajak-assi* with long main axis [3]. *K. alvarezii* var. *alvarezii* grows on reef flat limestone rocks; *K. alvarezii* var. *tambalang* on turbulent water of shallow reef flats; and *K. alvarezii* var. *ajak-assi* prefers flowing water with high nutrient and light. Zucharello et al. (2006) [7] used molecular analysis based on the mitochondrial *cox*2-3 and plastidal RubisCo spacers to investigate the systematics and genetic variation of 137 samples of commercial *Kappaphycus* and *Eucheuma*, including some wild strains.

Kappaphycus was shown to be distinct from *Eucheuma*; *K. alvarezii* ("cottonii") and *K. striatum* ("sacol") are genetically distinct; however the markers did not distinguish all the morpho-types of *K. alvarezii*. A larger sample size as well as the use of more variable molecular markers are needed to solve the identification of the morpho-types of *Kappaphycus* and *Eucheuma*.

FARMED *KAPPAPHYCUS* AND *EUCHEUMA* IN SABAH

Many varieties of *Kappaphycus* and *Eucheuma* are found in the farms around Sabah, east Malaysia. These varieties, their common names and their gel strengths, as determined by using the Steve Plotter (Danisco's Protocol) on 1.2% gel, at the Omni-Gel Laboratory, Sabah are given in Table 1. About six varieties were collected by Dr. Gan of Omni-Gel Company, with gel strength ranging from 250 to 500 $g.cm^{-2}$. The brown *tambalang* variety is popular because of the high gel strength. The following is a simple description of gross morphological features that may be used in the field for differentiating the main varieties cultivated in Semporna, Malaysia.

i) *K. alvarezii* var. *tambalang* (Figures 6-9)

There are around three sub-varieties of this *tambalang*, named Green *Tambalang*, Brown *Tambalang* and Giant *Tambalang*. There is another known as Buaya *Tambalang* growing in deeper water.

The *tambalang* appears bushy with dichotomous to irregular branching. The long, cylindrical main branches are covered with lateral branches with pointed tips.

ii) *Aring-aring* (*K. alvarezii)* (Figure 10)

This variety has a finer thallus with very short lateral branches with pointed tips. The plant has a greener hue when grown in shallower (<1m) water compared to the brown colour when grown at 2m from surface.

iii) Durian (*K. alvarezii*) (Figure 11)

This variety has cylindrical branches with wide angles between branches. The lateral branches are short, thick and appear as stiff broad spines, crowded near the tips of main branches. The whole plant looks like the durian fruit.

iv) Loving Beauty (*K. alvarezii*) (Figure 12)

This variety has a thallus morphology intermediate between the *tambalang* and durian varieties. The lateral branches are flexous, located nearer the distal ends of main branches, and the tips may be rounded.

v) Flower (*K. striatum* var. *sacol*) (Figure 13)

The Flower or *sacol* variety has three sub-types with differing colour (viz. green, brown and red). The variety which is commonly farmed has a greenish hue to the brown colour. The compact cylindrical thallus is densely covered with very short lateral branches crowded near the tips of the main branches, with broad angles between main branches, and giving the whole plant the shape of a dense head of flowers. Associated with this is also the *Katunai* varieties (Green *Katunai* and Brown *Katunai*) (Figures 14-15)

vi) *Spinosum* (*Eucheuma*) (Figure 16)

This is probably *E. denticulatum*. The thallus is irregularly branched. The long cylindrical branches are covered with short spines throughout distinguishing it from the generally smooth cylindrical thallus of *Kappaphycus*.

UTILISATION OF *KAPPAPHYCUS* AND *EUCHEUMA*

The *Kappaphycus* and *Eucheuma* farmed in east Malaysia is mainly used for carrageenan production. Two factories in Sabah were started in 2000 to produce semi-refined carrageenan, including carrageenan chips. Tacara is located in Morotai, Tawau while Omi-Gel is located at Jalan Kemiri, Semporna. The first successful farm for *Kappaphycus* (tambalang variety) in Peninsular Malaysia, has been established on Pangkor Island by Mr. Beh Wong King.

The farm has only been operating for less than a year and about 400kg FW can be harvested from 200m monolines in one month (pers. comm., Mr. Beh). The seaweed is presently dried for sale as a herbal material. Figures 17-18 show the monolines and the product. Traditionally, the *Kappaphycus* is cultivated for 45 days and continues for eight months of the year [8].

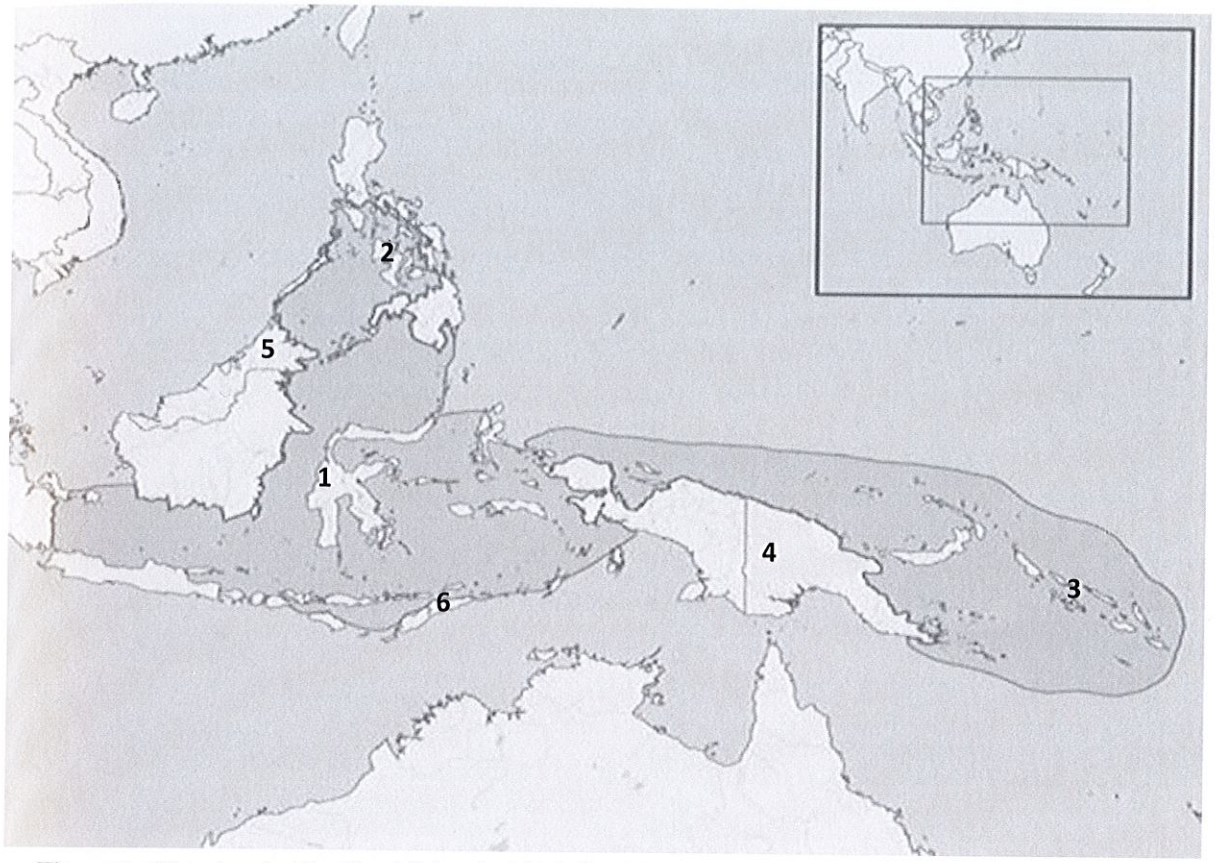

Figure 1: Map showing the Coral Triangle (shaded) which comprises six countries: 1: Indonesia; 2: Philippines; 3: Solomon Islands; 4: Papua New Guinea; 5: Malaysia; 6: Timor Leste. (SeaPlant.net)

Table 1: List of *Kappaphycus* and *Eucheuma* varieties farmed in Malaysia and their gel strengths.

	Seaweed variety (common name)	Scientific name	Collection Locality	Gel strength using the Steve Plotter Method (1.2% gel) $g.cm^{-2}$
1	Green *tambalang*	*K. alvarezii* var. *tambalang*	Semporna	>550
2	Brown *tambalang*	*K. alvarezii* var. *tambalang*	Semporna	>550
3	Giant *tambalang*	*K. alvarezii* var. *tambalang*	Semporna	N/A
4	Buaya tambalang (deeper water)	*K. alvarezii* var. *tambalang*	Semporna	N/A
5	*Aring-aring* (grown at <1m)	*K. alvarezii*	Semporna	> 500
6	*Aring-aring* (grown at 2m)	*K. alvarezii*	Semporna	>500
7	Durian	*K. alvarezii*	Semporna	>450
8	Loving beauty	*K. alvarezii*	Semporna	>550
9	Flower (*sacol*)	*K. striatum* var. *sacol*	Semporna	>550
10	Katunai (green)	*K. striatum*	Semporna	N/A
11	Katunai (brown)	*K. striatum*	Semporna	N/A
12	*Spinosum*	*E. denticulatum*	Semporna	>250

Figure 2: *Kappaphycus* farm in Semporna, Sabah. (Photo credit: Mushidi bin Hassan)

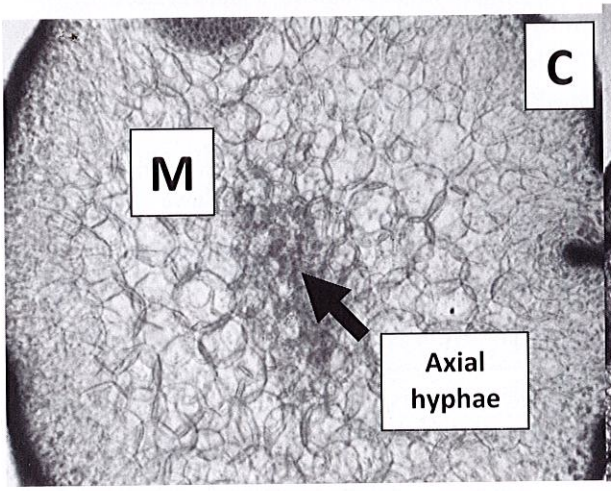

Figure 3: Cross-section of *Kappaphycus* thallus. C: Cortex made up of smaller outer cortical cells and inner radially elongated cells; M: Medulla made up of large rounded cells, with a central core narrow filaments forming the axial hypha.

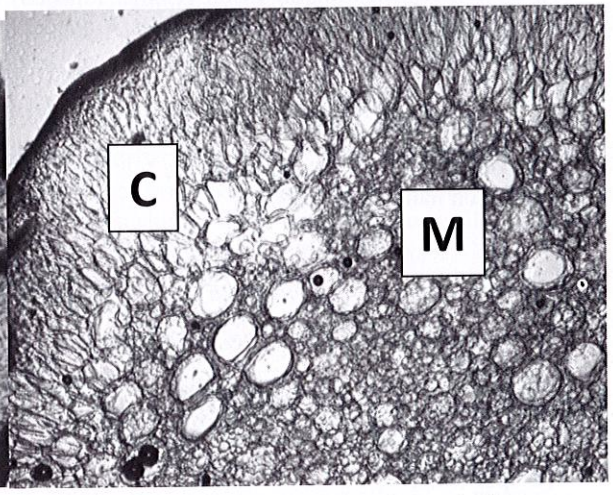

Figure 4: Cross-section of *Kappaphycus* thallus. C: Cortex, made of smaller radiating cortical cells M: Pseudoparenchymatous medulla, made of larger, rounded cells mixed with smaller cells.

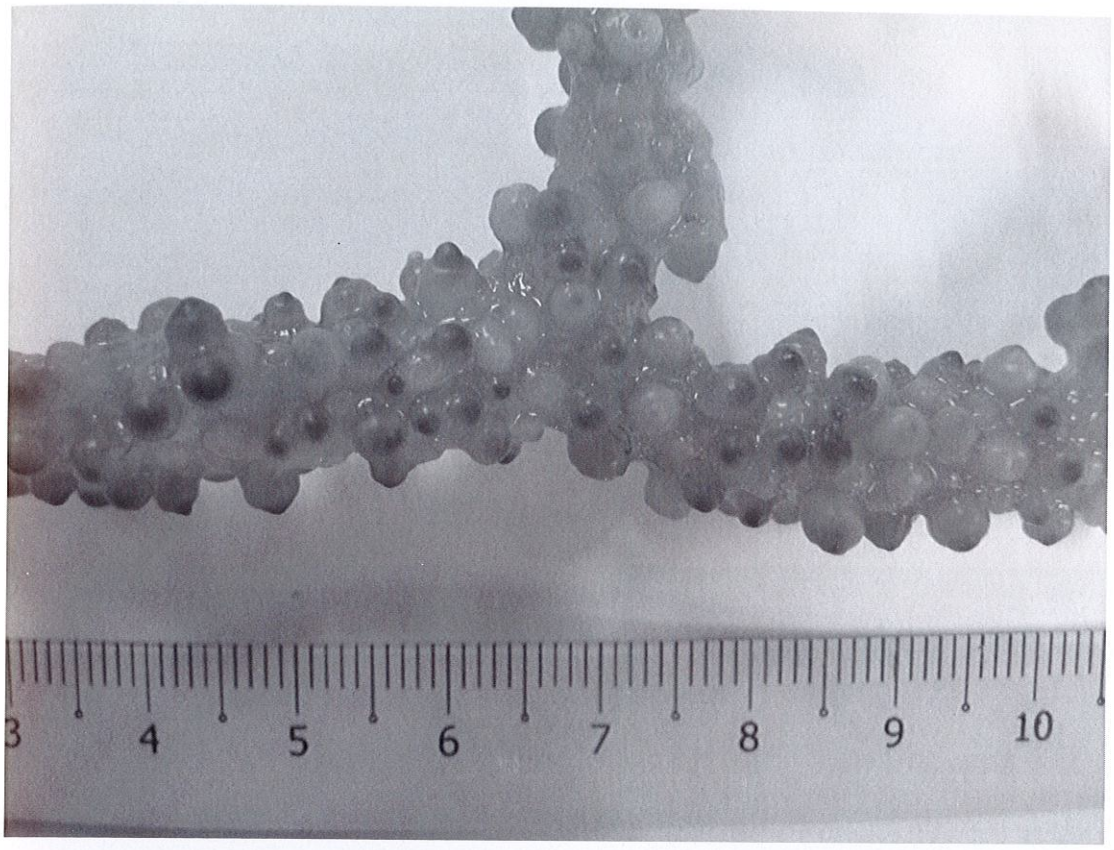

Figure 5: The reproductive structures known as cystocarps (carposporangia) are scattered all over the surface of the *Kappaphycus* thallus.

Figure 6a: *Kappaphycus alvarezii* var. *tambalang* (Green *tambalang*)

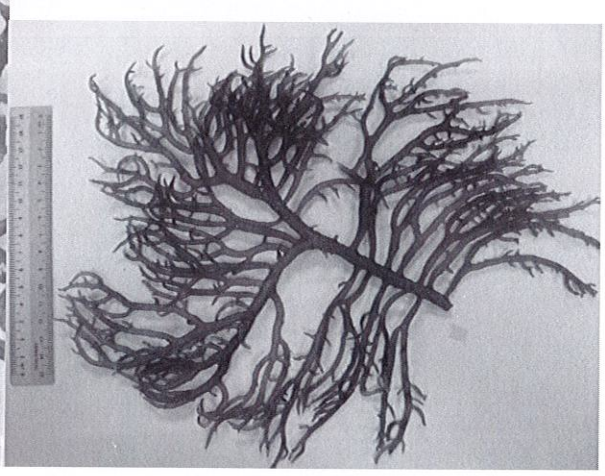

Figure 6b: *Kappaphycus alvarezii* var. *tambalang* (Green *tambalang*)

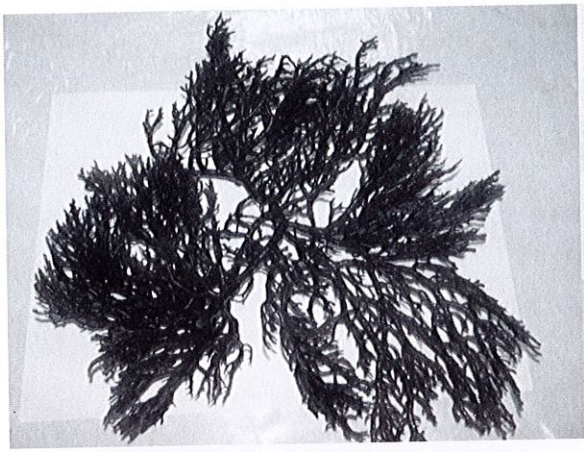

Figure 7a: *Kappaphycus alvarezii* var. *tambalang* (Brown *tambalang*)

Figure 7b: *Kappaphycus alvarezii* var. *tambalang* (Brown *tambalang*)

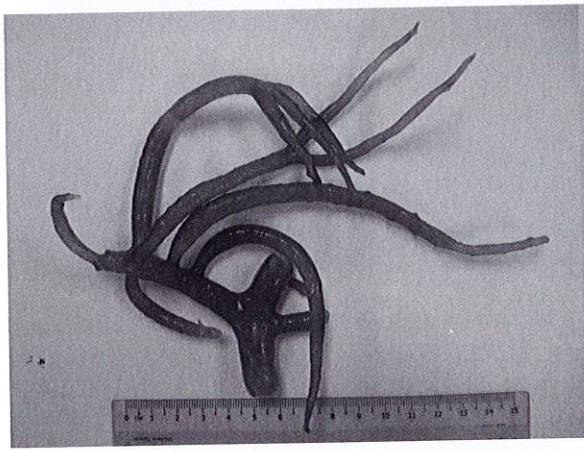

Figure 8: *Kappaphycus alvarezii* var. *tambalang* (Giant *tambalang*)

Figure 9a: *Kappaphycus alvarezii* var. *tambalang* (Buaya *tambalang*)

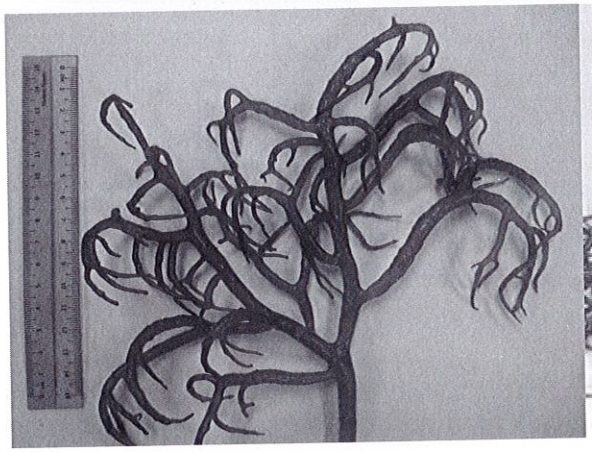

Figure 9b: *Kappaphycus alvarezii* var. *tambalang* (Buaya *tambalang*)

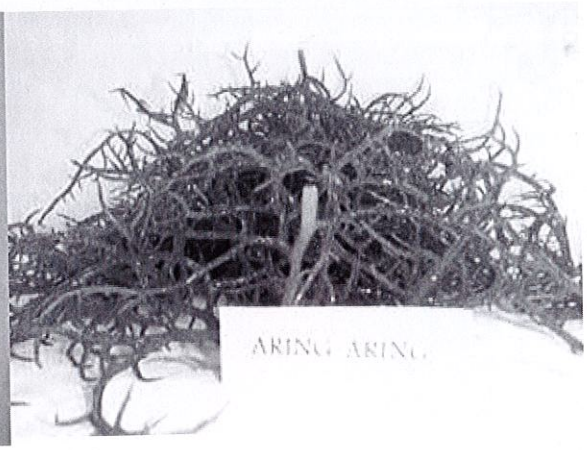

Figure 10a: *Kappaphycus alvarezii* (*Aring-aring*)

Figure 10b: *Kappaphycus alvarezii* (*Aring-aring*, < 1 meter depth)

Figure 10c: *Kappaphycus alvarezii* (*Aring-aring*, > 2 meter depth)

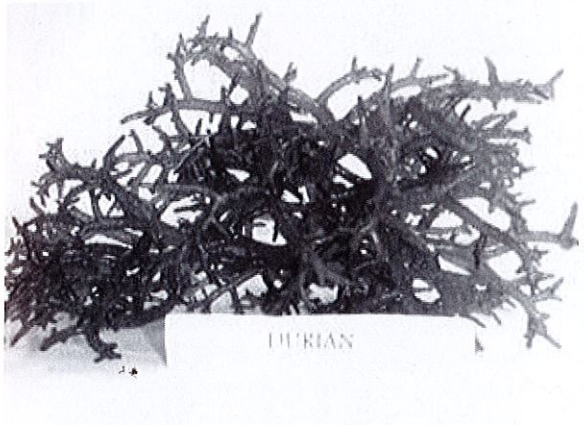

Figure 11: *Kappaphycus alvarezii* (Durian)

Figure 12: *Kappaphycus alvarezii* (Loving Beauty)

Figure 13: *Kappaphycus striatum* var. *sacol* (Flower)

Figure 14: *Kappaphycus striatum* var. *sacol* (Katunai green)

Figure 15: *Kappaphycus striatum* var. *sacol* (Katunai brown)

Figure 16a: *Eucheuma denticulatum* (Spinosum)

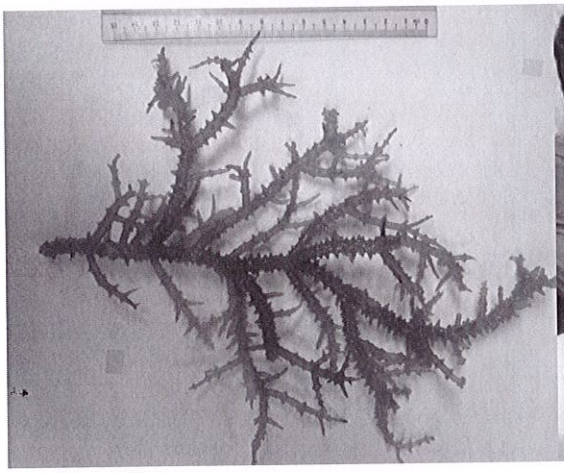

Figure 16b: *Eucheuma denticulatum* (Spinosum)

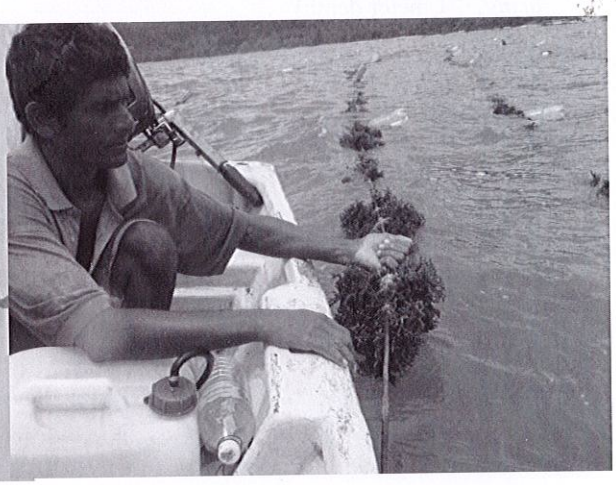

Figure 17: The monocline culture of *Kappaphycus* in Pulau Pangkor, Peninsular Malaysia

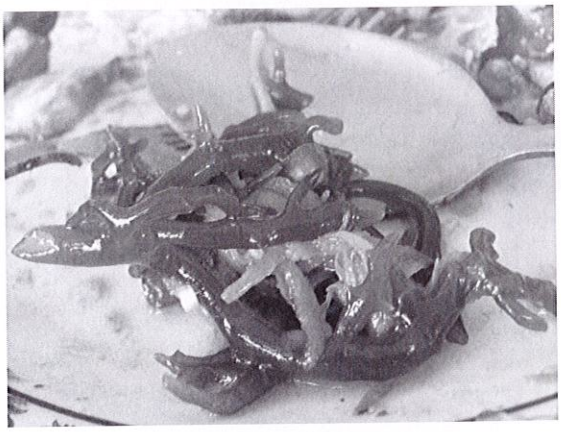

Figure 18: A salad made from freshly harvested *Kappaphycus* from the Pulau Pangkor farm.

Figure 19: Seaweed herbal drink

The monthly production from Semporna is around 150 to 350 MT DW per month. Biomass increases from the initial 0.1 to 0.2 kg per stocking bunch to 0.5 to 0.7 kg in 45 days. The maximum production capacity in Semporna is around 1.5 MT per hectare per month. The harvested seaweed is sun dried on the platforms of houses built on the reefs and sold with moisture content of 38 to 50%. Current selling price fluctuates around RM2.80 (USD 0.85) for moisture content of 50%.

Together with other seaweeds like *Caulerpa*, *Solieria* and *Gracilaria* which are collected from the wild, the farmed *Kappaphycus* is sold in the local markets in Sabah for consumption as salads, soups and puddings [9]. Recently, health drinks, cordials, jelly cups, jams, chilli sauce and shampoo, have been produced from the *Kappaphycus* (Figures 19-21). Three patents have been filed in Malaysia on the use of the seaweeds for enhancing hair growth, wound-healing and anti-cancer nutraceutical.

CONCLUDING REMARKS

It is the objective of this short communication to record the many varieties of *Kappaphycus* and *Eucheuma* presently farmed in Malaysia. This is not a complete taxonomic nor systematics account; better understanding of the taxonomy of the many varieties described here can only be obtained through molecular analysis. While it has been shown that gel strength may differ amongst the many varieties, it should be remembered that many factors influence both the growth and chemical composition of seaweeds. Hurtado *et al.* (2008) [10] showed that stocking density, culture period, and water depth affects the growth rate, carrageenan content and molecular weight of *K. striatum* var. *sacol*.

The best conditions recommended for *sacol* is stocking density of 500g.per m per monoline at a water depth of 50 to 100cm for 30 days of culture. Diseases like the *ice-ice* caused depolymerisation of the carrageenan and resulted in decrease in gel strength as well as in carrageenan yield, viscosity and increase in syneresis index, in *K. striatum* var. *sacol* [11]. Epiphyte infestations have also been associated with reduced seaweed production and reduced carrageenan quality [12]. The epiphytic *Neosiphonia* produced "goose-bump" cortical swellings on the thallus of *Kappaphycus alvarezii* which resulted in pits which were then infected with opportunistic bacteria like *Alteromonas*, *Flavobacterium* and *Vibrio* as secondary infections.

To aid in the development of a viable, competitive carrageenan industry in Malaysia, the following actions are recommended:

i) Standard protocols for strain identification and selection.
To address this, DNA fingerprinting methods have to be developed. Complete database of phycocolloid characteristics (type, yield, gel strength), growth requirements, disease and epiphyte resistance, etc.

ii) Strain improvement focusing on disease resistance, good carrageenan quality and even adaptation to climate change.

iii) Use Recombinant techniques in addition to traditional hybridization and selectionmethods. Generate ESTs or sequence the genome of *Kappaphycus*. The mining of useful genes will lead to strain improvement and discovery of new products.

iv) Improved farming methods. Develop epiphyte control, nurseries for spore, tissue culture and seed production. Develop co-culture of seaweeds with shellfish, fish and other seafood species, as well as integrated aquaculture systems.

v) New downstream products. Formulate new value-added products; eg. food, feed, cosmeceuticals, nutraceuticals, beverages, confectionaries, etc.

vi) Increased farming area and formulate farmer motivation and training activities.

The industry requires sources of consistent carrageenan quality; pure kappa-carrageenan or pure iota-carrageenan, not mixed together, as is often encountered in the market [13]. The availability of a good database and key to the various varieties of *Kappaphycus* and *Eucheuma* farmed in Malaysia, will allow our farmers to select and focus on the best varieties for each type of carrageenan. Cooperation between the industry, the farmers, the relevant government departments and the university researchers, is essential to provide this very important element necessary for the development of a viable and competitive seaweed industry for Malaysia.

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Figure 20: Seaweed chilli sauce

Figure 21: Seaweed shampoo