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Seaweed as potential plant growth stimulants for agriculture in Mexico

Las algas como potenciales estimulantes del crecimiento vegetal para la agricultura en México

Rosalba Mireya Hernández-Herrera[1], Fernando Santacruz-Ruvalcaba[1], Diego Ramón Briceño-Domínguez[2], Dania Andrea Di Filippo-Herrera[3] and Gustavo Hernández-Carmona[3]

[1]Laboratorio de Biotecnología, Departamento de Botánica y Zoología, Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara. Calle Ramón Padilla Sánchez 2100, Col. Nextipac, Zapopan, Jalisco, 45110. México
[2]Laboratorio de Ciencias Básicas, Instituto Tecnológico Superior de Felipe Carrillo Puerto. Carretera a Vigia Chico Kilómetro 1.5, Centro. Felipe Carrillo Puerto, Quintana Roo, 77200. México
[3]Laboratorio de Química de Algas Marinas. Departamento de Desarrollo de Tecnologías, Centro Interdisciplinario de Ciencias Marinas (CICIMAR), Instituto Politécnico Nacional. Av. Instituto Politécnico Nacional S/N Col. Playa Palo de Santa Rita, La Paz, Baja California Sur, 23096. México
e-mail: gcarmona@ipn.mx

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ABSTRACT

Background. One of the promising directions in agriculture is the rational use of biologically active substances or plant growth stimulators obtained from local raw materials. In Mexico, seaweed can be considered a cheap, abundant, and accessible local resource along the Mexican coast. It represents great potential for eventual commercial exploitation as a source of plant growth promoters. Previous reports have emphasized the importance of seaweed extracts and their utilization with significant results to improve seed germination, seedling development, growth, and yield of plants, increasing crop productivity. The main effects should be in the first stages of plant ontogenesis, beginning with seed germination and seedling growth. The effects of seaweed liquid extracts in the early stages of plant growth are on root-system growth, providing a signal of the value and quality of the future crop. Therefore, the search for the most effective extracts that stimulate plant development is considered a priority. **Goals**. Show an overview of the application of seaweed extracts in Mexican agriculture. **Results**. Information is provided on the administration and regulation for the harvest of marine algae, and the research carried out in Mexico. The management and harvest regulations for the algae, including seaweed liquid extract composition, biological efficacy of promoting plant growth, as well as elicitors of disease defense caused by pathogens. **Conclusions**. Seaweeds from Mexico have enough potential for the isolation of biologically active compounds that could increase agriculture productivity. This research is essential for the future of Mexican agriculture, to develop effective strategies to use seaweed extracts.

Keywords: agriculture, biostimulants, extracts, seaweeds

RESUMEN

Antecedentes. Una de las áreas prometedoras en la agricultura es el uso racional de sustancias biológicamente activas como estimulantes del crecimiento de plantas, obtenidos de materias primas locales. En México, las algas marinas pueden ser consideradas como un recurso local económico a lo largo de su costa, que está disponible y en abundancia. Representa un gran potencial para su eventual explotación comercial como bioestimulante del crecimiento de las plantas. En estudios previos se ha enfatizado la importancia de los extractos de algas y su uso con resultados significativos para mejorar la germinación de las semillas, el crecimiento y el rendimiento de las plantas, acrecentando la productividad de los cultivos. Por lo tanto, la búsqueda de extractos efectivos que estimulan el desarrollo de las plantas se considera prioritaria. **Objetivos**. Mostrar una visión general de la aplicación de extractos de algas marinas en la agricultura mexicana. **Resultados**. Se muestra la diversidad de la flora algal con potencial como biofertilizante y se presenta una reseña histórica del manejo y regulaciones de cosecha en México. Se describe la industria mexicana de los extractos de las algas con aplicación en la agricultura, incluyendo la composición química de los extractos algales, su eficacia biológica en el crecimiento de las plantas, así como inductores de defensa contra enfermedades causadas por patógenos. Además, se indican las investigaciones actuales del uso de extractos de algas en algunos cultivos. **Conclusiones**. Las algas marinas de México tienen un alto potencial para el aislamiento de compuestos biológicamente activos que podrían aumentar la productividad agrícola. La información presentada es esencial para que, en un futuro, la agricultura mexicana desarrolle estrategias efectivas del uso de extractos de algas marinas.

Palabras clave: agricultura, algas marinas, bioestimulantes, extractos

INTRODUCTION

Many species of seaweeds, mainly brown algae, are widely used in agriculture as plant biostimulants, plant growth regulators, biofertilizers, or metabolic enhancers (Hong *et al.*, 2007). Seaweed extracts can act by increasing plant vigor and vitality due to the presence of several bioactive substances that are important for plants (Khan *et al.*, 2009; Gupta & Abu-Ghannam, 2011). Also, they can improve nutrient uptake from soil (Turan & Köse, 2004). There are many advantages of using seaweed extracts as stimulants of plant growth, including higher germination rates, root-system development, increased leaf area, fruit quality, and plant vigor (Hong *et al.*, 2007; Rayorath *et al.,* 2008; Khan *et al.,* 2009; Craigie, 2011; Vinoth *et al.,* 2012a, b; Mattner *et al,.* 2013; Vinoth *et al.,* 2014). Besides this, plants treated with seaweed extracts have a higher content of biochemical constituents such as chlorophyll, carotenoids, protein, and amylases (Zhang & Schmidt, 2000; Thirumaran *et al.*, 2009; Gireesh *et al.*, 2011), and treated plants acquire more resistance against pathogens (Jayaraj *et al.*, 2008; Vera *et al.*, 2011a, b; González *et al.*, 2013a, b; Satish *et al.*, 2015a, b; Ali *et al.*, 2016).

As these beneficial effects are obtained with small doses of seaweed extracts, it is suggested that the active compounds could be growth hormones that occur naturally in seaweeds, such as auxins, cytokinins, gibberellins, or other low molecular weight components (polyamines and brassinosteroids) that are also effective at low concentrations (Hernández-Herrera *et al.*, 2016). In addition, higher components identified in algal extracts such as polyphenols (phloroglucinol and its derivate eckol) promote growth activity, as well as polysaccharides (alginate, fucoidan, laminaran, and carrageenans, or their derived oligosaccharides) exhibit the same growth promotion activity (Hong *et al.*, 2007; Khan *et al.*, 2009; Craigie, 2011; González *et al.*, 2013b; Rengasamy *et al.*, 2015a, b). Other studies also indicate that the biostimulants effect is synergistically produced by all extract components: carbohydrates, proteins, minerals, vitamins, fatty acids, and phytohormones (Fornes *et al.*, 2002; Zamani *et al.*, 2013).

Recently in Mexico, the use of seaweed derivatives as biostimulants, biofertilizer, metabolic enhancer, and root promoters are included in crops as an alternative to the use of synthetic fertilizers, in order to reduce ecosystem degradation and contamination of agricultural land (Hernández-Herrera *et al.*, 2014a). These reports show that a better understanding of their biological mode of action may enhance productivity in the future. The status and context for seaweed applications in Mexican agriculture are presented here.

DIVERSITY OF SEAWEED FLORA WITH POTENTIAL AS BIOFERTILIZERS

Mexico is the only Latin American country with temperate, subtropical, and tropical seas; thus, no other country in this region has such diversity in the marine environment (Robledo *et al.*, 2013). The coastline of Mexico extends for ~11,500 km (7,146 miles) and the exclusive economic zone covers approximately 3 million square kilometers. Five geographic regions in temperate to tropical latitudes with distinctive physiographic, geological, and climatic conditions favor the existence of a diverse algal flora. I) Baja California has an extensive latitudinal range and varied climatic patterns with the richest seaweed flora and large potential; 60 species cited as economically important are present (Aguilar-Rosas, 1982). II) The Gulf of California is considered an area of abundant seaweed with potential economic value; at least 55 species have commercial application (Pacheco-Ruíz & Zertuche-González, 1996) and there is high biomass which can be harvested sustainably. III) The Tropical Pacific is characterized by an impoverished phycoflora, with most species in the Rhodophyta and Phaeophyceae taxonomic groups (Pedroche & Sentíes, 2003). Of the few studies addressing economic potential of seaweed none occur in the tropical region of Nayarit and Jalisco. Respectively, these areas have 16 and 4 species with potential for exploitation to produce seaweed liquid extracts for agriculture (Pacheco-Ruíz & Zertuche-González, 1996; Hernández-Herrera *et al.*, 2014a; Nicolás-Álvarez *et al.*, 2014; Hernández-Herrera *et al.*, 2016). However, algal biomass, populations, and ecological studies of seaweeds with economic interest are unknown for the region. IV) In the Gulf of Mexico, the flora has a continuous distribution (Garduño-Solórzano *et al.*, 2005) represented by species of *Ulva* as having economic potential. V) The Mexican Caribbean has cold and warm water currents, influencing the distributional pattern of seaweeds, which is associated with the littoral and sub-littoral rocky areas; 28 species of seaweed with economic interest are recognized on the Yucatan coast (Robledo-Ramírez & Freile-Pelegrín, 1998). The richest seaweed flora and potential for seaweed utilization in Mexico is shown in Figure 1.

MANAGEMENT AND REGULATIONS IN MEXICO FOR THE EXPLOITATION AND HARVESTING OF SEAWEED

In Mexico, the federal government manages all fisheries, including seaweed. However, under a law published in 2009, individual states can also manage sessile marine resources through an agreement with the federal government (Calvillo-Unna, 2009). Currently in Mexico, artisans carry out the harvest of this resource. For example, since 1966, *Chondracanthus canaliculatus* (Harvey) Guiry has been harvested by hand at low tide for carrageenan production. It is a sustainable harvest to date in San Quintin, Baja California. Aquaculture and harvesting of *Kappaphycus alvarezii* (Doty) Doty ex P.C.Silva in Dzilam de Bravo, Yucatan, is done by both men and women (Robledo *et al.*, 2013; Rebours *et al.*, 2014). At present, the harvest of this resource (such as in the case of *Gelidium robustum* (Gardner) Hollenberg et Abbott and *Macrocystis pyrifera* (Linnaeus) C. Agardh in Baja California), is carried out with small boats, where two fishermen using knives cut the upper portion of the alga; the maneuver typically requires 2 to 4 hours of labor (DOF, 2012).

THE MEXICAN SEAWEED EXTRACT INDUSTRY

In Mexico, the use of seaweed at an industrial level started in the first half of the last century. The agar industry began in 1941 with the Alga-Mex company (Osario-Tafall, 1946) harvesting the 'red sargazo' *Gelidium robustum* by diving. Currently, *G. robustum* is the only algae processed in Mexico by the company Agarmex. The giant kelp *Macrocystis pyrifera* along with other algae of the genus *Sargassum* were initially exploited in Isla Todos Santos (Baja California), where potassium salts were obtained for agricultural purposes (Ortega, 1987), but the industry began in 1956 harvesting kelp as a source of alginates. One decade later, locals started harvesting *Chondracanthus canaliculatus* as a source of carrageenan, by hand during low tide.

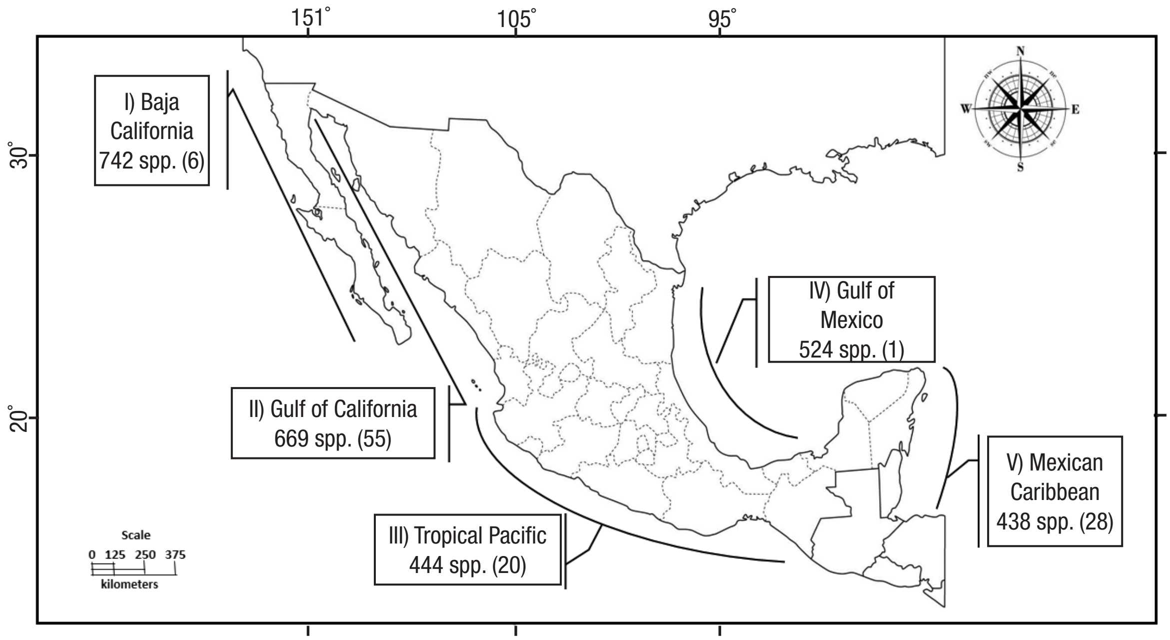


Figure 1. Seaweed flora in the five geographic regions of Mexico according to Pedroche and Sentíes (2003). The number of seaweeds with potential economic value appears in parenthesis.

For almost four decades, the Mexican industry remained in good shape; however, some important changes occurred in 2004, because the alginate industry shut down in the USA (CP Kelco), causing Mexico to stop exporting *M. pyrifera.* From 1956 to 2004, an annual average of 3,000 tons were harvested, using a boat designed specifically to harvest the available biomass, cutting the surface frond at one meter below the surface. The closing of this activity led to the search for other uses for *M. pyrifera*, such as the production of a supplement for balanced meals to feed red abalone [*Haliotis rufescens* (Swainson)]. The production of seaweed liquid extracts for application in agricultural crops also started. At present, Mexico's seaweed biomass, such as *Gelidium robustum* and *Chondracanthus canaliculatus* is sold to the phycocolloid industry for agar and carrageenan extraction (DOF, 2012; Zertuche-González *et al*., 2014). At present, *G. robustum* and *M. pyrifera* are used by the Algas Pacific company (http://algaspacific.com/) located in Ensenada in Baja California state, to produce seaweed liquid extracts, which are sold as a plant growth biostimulant. None of the four commercial seaweed species harvested in Mexico (*M. pyrifera*, *G. robustum*, *C. canaliculatus*, *Gracilariopsis lemaneiformis* (Bory de Saint-Vincent) E.Y. Dawson, Acleto y Foldvik) is endangered, thanks to the application of proper harvesting methods (Hernández-Garibay *et al*., 2006; Robledo & Townsend, 2006; DOF, 2012).

Seaweed liquid fertilizer production is carried out by the private sector, which harvests and processes its raw materials. There are few companies working on liquid fertilizer production, employing ~10 fishermen in algal harvesting and processing, from which about 20 more families benefit. The use of raw materials for food benefits about 20 families directly and indirectly, and it is increasing (DOF, 2012).

Algal biomass from six seaweed species are used to produce 14 commercial products (SAGARPA, 2012) such as biostimulants, biofertilizers, and root promoters (Table 1). According to our research, the production of commercial products in Mexico is based on algae biomass by conventional solvent extraction and hydrolysis with several methods under hydrothermal treatment with acid, neutral, and alkaline conditions.

THE EFFECT OF SEAWEED AND ITS DERIVATES ON GERMINATION AND SEEDLING ESTABLISHMENT

The seaweed liquid extracts for plant biostimulants produced in Mexico compete with similar products described by other authors. In published research (Table 2), trials were conducted in Mexico with 12 seaweed species to test biostimulant activity on crop growth.

The use of liquid seaweed extracts in Mexico began around the 1980s with the commercial product Algaenzims. Canales-López (1999) published a compilation of 12 years of research to find the precise doses of seaweed enzymes and the effects on plants and crop quality, as well as changes in the soil. The results showed a crop increase to 1-3 t ha^{-1} by supplying from 1-3 L ha^{-1} of the commercial product produced in the region. Another study by Villarreal-Sánchez *et al.* (2003) showed that Algaenzims contains a complex of viable (live) sea microorganisms, which includes nitrogen-fixing organisms, halophiles, molds and yeasts, and macro and microelements that highlight the importance of interactions between plants and the microorganisms contained in the product.

Additional research by García-Sahagún *et al*. (2014) assessed the effect of a commercial product (seaweed) on the development of gerbera (*Gerbera jamesonii* H. Bolus) under greenhouse conditions. Applying seaweed to gerbera had a positive effect on leaf number, stem number, stem length, and capitulum or flower head diameter (Fig. 2).

Figures 2a-c. a) Capitulum harvested according to treatment. From left to right, Seaweed (SW), Alga 600 (A600), Control (T), and Osmocalm (PN); b) Length of stems; c) Diameter of the capitulum. (Photos: María Luisa García Sahagún).

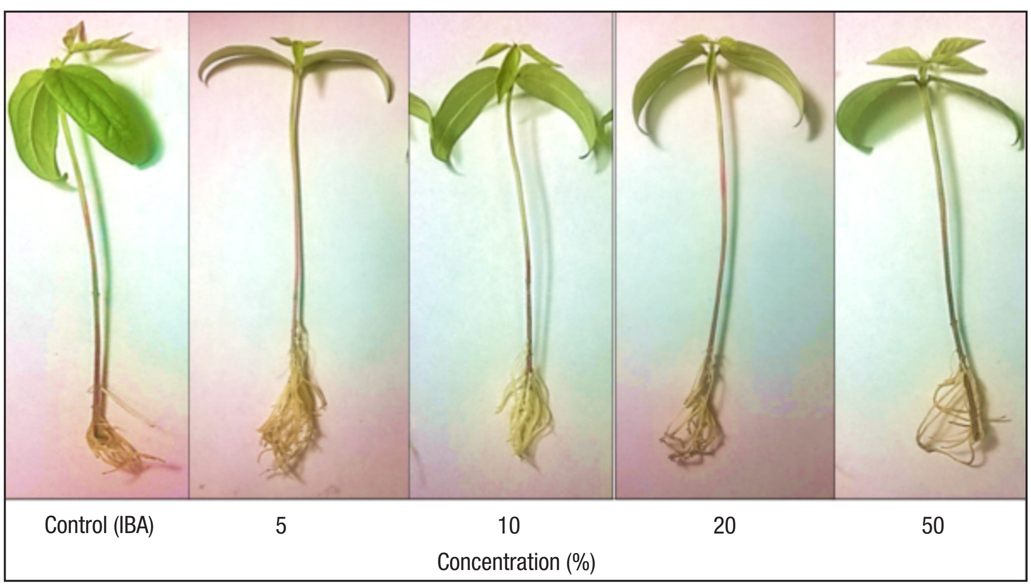
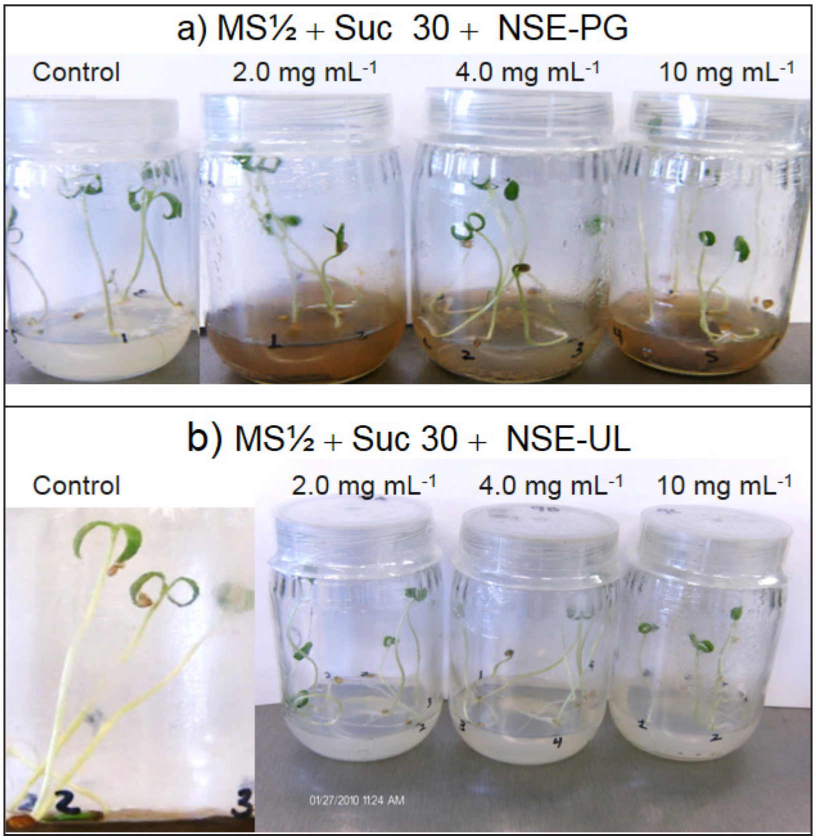


Figure 3. Activity of the extracts of *Macrocystis pyrifera* (Linnaeus) C. Agardh produced at different pH and temperature on the adventitious root formation from bean mung plants and IBA as reference (control).

Table 1. Commercial seaweed products produced in Mexico.

Product name	Seaweed species	Manufacturer	Application	pH/color	Reference
AgroKelp®	*Macrocystis pyrifera* (Linnaeus) C. Agardh	Algas y Bioderivados Marinos, S.A de C.V	Biostimulant Biofertilizer	4.3-4.6 Dark brown liquid	Khan *et al*. (2009), Sharma *et al*. (2014)
Algaenzims[MR]	*Sargassum* spp., desert plants and salts	Palau Bioquim, S.A. de C.V	Biofertilizer	Unspecified	Sunapri *et al*. (2010), Villarreal-Sánchez *et al*. (2003)
Algamar®	*Ascophyllum nodosum* (Linnaeus) Le Jolis*, Sargassum* spp.*, Laminaria* spp.*, M. pyrifera,* and *Egregia menziesii* (Turner) Areschoug	Química Sagal, S.A. de C.V	Biostimulant	8.7-9.3 Black powder	In this study
Algaroot[MR]	*Sargassum* spp., desert plants and salts	Palau Bioquim, S.A. de C.V	Root promoter	Unspecified liquid	In this study
Cuajaenzims[MR]	*Sargassum* spp., desert plants and salts	Palau Bioquim, S.A. de C.V	Biostimulant	Unspecified	In this study
Frutoenzims[MR]	*Sargassum* spp., desert plants and salts	Palau Bioquim, S.A. de C.V	Biostimulant	Unspecified	In this study
Kelpro[MR]	*M. pyrifera* and *E. menziesii*	Tecniprocesos Biológicos, S.A. de C.V	Biostimulant	4.4	Khan *et al*. (2009), Sharma *et al*. (2014)
Kelprolizer®	*M. pyrifera,* liquid fish protein and humic acid	Productos del Pacífico, S.A de C.V	Blend organic fertilizer	4.5-5.0	In this study
Kelproot®	*M. pyrifera* and *Gelidium robustum* (Gardner) Hollenberg et Abbott	Algas y Extractos del Pacífico Norte, S.A. de C.V	Root promoter	2.0 to 12.5 Dark brown liquid	In this study
Kelprosoil®	*M. pyrifera*	Productos del Pacífico, S.A de C.V	Biostimulant	Brown to greenish liquid	Khan *et al*. (2009), Sharma *et al*. (2014)
NPKelp®	*M. pyrifera* and *G. robustum* combined with *Yucca schidiger*a Roezl ex Ortgies and humic acid	Algas y Extractos del Pacífico Norte, S.A. de C.V	Biofertilizer	4.5-5.1 Dark brown liquid	In this study
Seaweed®	*M. pyrifera*	Algas Marinas, S.A. de C.V	Biostimulant	4.0-4.5 brown	In this study
Turboenzims[MR]	*Sargassum* spp.*,* desert plants and salts	Palau Bioquim, S.A. de C.V	Metabolic enhancers	Unspecified	In this study
Vitalex®	Unspecified seaweed and hydrolyzed fish	Química Sagal, S.A. de C.V	Biofertilizer	8.5-9.0 Brown liquid	In this study

In recent published research by Briceño-Domínguez *et al*. (2014), a new method was developed to produce an alkaline seaweed liquid extract from *M. pyrifera* with high polysaccharide content. They suggested scaling up the process to industrial level. The most active extract was produced at pH 12 and 80 °C. Under these conditions the seaweed liquid extract enhanced adventitious root formation in a mung bean cutting assay, similar to the effect of indole-3-butyric acid (IBA) (Figure 3), and increased seedling growth in tomatos. Additionally, Nicolás-Álvarez *et al*. (2014) also found that a crude extract of *Sargassum liebmannii* J. Agardh is a potential germination promoter for *Pachyrhizus erosus* (L.) Urban.



Figures 4a-b. Tomato (*Solanum lycopersicum* Linnaeus). Seedling growth under culture *in vitro* after two weeks of incubation exposed to different concentrations of seaweed extracts. a) Plants growing in control (half-strength MS with sucrose at 30 g L^{-1}) and in different concentrations of neutral seaweed extracts from *Padina gymnospora* (Kützing) Sonder (NSE-PG); b) Neutral seaweed extracts of *Ulva lactuca* Linnaeus (NSE-UL) combined in half-strength MS with sucrose (30 g L^{-1}).

Hernández-Herrera *et al*. (2014a, 2016) found that neutral and alkaline seaweed extracts as well as polysaccharide-enriched extracts produced with tropical marine algae increased seed germination and tomato plant growth under different culture conditions (Fig. 4). In addition, enhanced adventitious root formation was observed in mung bean cuttings with polysaccharide-enriched extracts obtained with neutral rather than alkaline conditions (Fig. 5). Similarly, acid seaweed extracts increased biochemical parameters (Chlorophyll, total and reducer sugar) in the mung bean (Castellanos-Barriga *et al*., 2017), as well as seed germination of red radish (unpublished data) (Fig. 6).

The effect of green and brown seaweed extracts as elicitors to protect tomatos (*Solanum lycopersicum* Linnaeus) against the necrotrophic fungus *Alternaria solani* (Cooke) Wint. was published in Mexico. The algal extracts increased the defense activity of enzymes and proteinase inhibitors and expression of defense-related genes (Hernández-Herrera *et al.*, 2014b).

CURRENT RESEARCH OF ALGAE EXTRACTS ON SOME CROPS

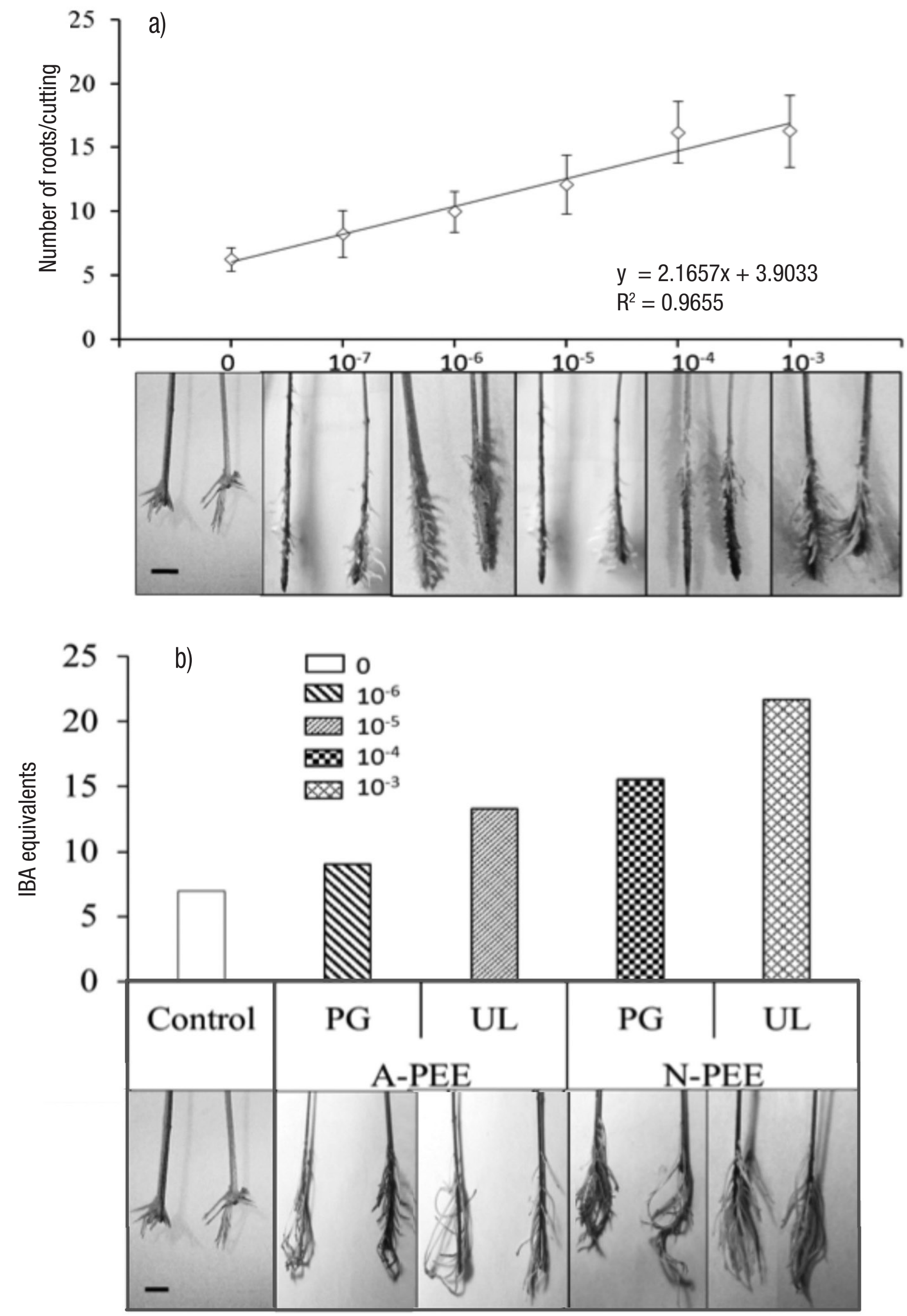
The effects of both liquid and solid seaweed-derived biostimulants, biofertilizers, and root promoters was studied in Mexico by CICIMAR (Interdisciplinary Center of Marine Sciences of the National Polytechnic Institute, CUCBA (University Center for Biological and Agricultural Sciences, acronym in Spanish) at the University of Guadalajara, and the Technical Superior Institute of Felipe Carrillo Puerto in Quintana Roo state, and included the following species: *Macrocystis pyrifera*, *Ecklonia arborea* (Areschoug) M.D. Rothman, Mattio & J.J.Bolton (=*Eisenia arborea*), *Sargassum liebmannii*, *S. horridum* Setchell & N.L. Gardner, *S. natans* (Linnaeus) Gaillon, *S. fluitans* (Børgesen) Børgesen, *Padina gymnospora* (Kützing) Sonder, *Chnoospora minima* (Hering) Papenfuss, *Caulerpa sertularioides* (S.G. Gmelin) M. Howe, *Ulva lactuca* Linnaeus, *Acanthophora spicifera* (M. Vahl) Børgesen, *Gelidium robustum*, and *Gracilaria parvispora* I.A. Abbott. These products were produced by acid, neutral, or alkaline extraction techniques.

The results obtained from this research could be useful to write a best-practice guide for regional agriculturists to improve harvesting quantity and quality in agriculture and horticulture. In conclusion, this review showed that seaweed extracts and polysaccharide-enriched extracts are increasingly used in Mexican crop production. Research in our laboratories demonstrated that crop species respond differently to the extracts (concentration and frequency of application); yet more crop-specific research is required to optimize seaweed extract application and to obtain the best possible outcome (i.e. return on investment). Most of the seaweed extract products currently in the market are extracts of whole seaweed. A number of questions require answers for

Table 2. Seaweed used as biostimulant in crops.

Geographic regions	Seaweed used to produce the extracts	Type of extracts	Crops	Beneficial effects under crops	References
I Baja California	*Macrocystis pyrifera* (Linnaeus) C. Agardh	Alkaline	Bean mung (*Vigna radiata*) (L.) Wilczek and tomato (*Solanum lycopersicum* Linnaeus)	Growth promoter	Briceño-Domínguez *et al.* (2014)
	Macrocystis pyrifera (Linnaeus) C. Agardh	Alcoholic	Red radish (*Raphanus sativus* Linnaeus)	Root promoter	Hernández-Alarcón (2014)
	Ecklonia arborea (=Eisenia arborea J. E. Areschoug)	Alkaline	Bean mung, lettuce (*Lactuca sativa* Linnaeus) and red radish	Growth promoter	Martínez-Morales (2015)
II Gulf of California	*Acanthophora spicifera* (M.Vahl) Børgesen	Alkaline	Bean mung, lettuce and red radish	Root promoter	Martínez-Morales (2015)
	Ulva lactuca Linnaeus	Alkaline	Bean mung, lettuce and red radish	Root promoter	Martínez-Morales (2015)
	Ulva lactuca	Acid	Bean mung	Root promoter	Castellanos-Barriga *et al.* (2017)
III Tropical Pacific	*Caulerpa sertularioides* (S. G. Gmelin) M.Howe	Neutral	Tomato	Enhance germination	Hernández-Herrera *et al.* (2014)
	Padina gymnospora (Kützing) Sonder	Neutral	Tomato	Enhance germination	Hernández-Herrera *et al.* (2014)
	Sargassum liebmannii J. Agardh	Neutral	Tomato	Enhance germination	Hernández-Herrera *et al.* (2014)
	Ulva lactuca	Neutral	Tomato	Enhance germination	Hernández-Herrera *et al.* (2014)
	Padina gymnospora	Neutral and alkaline	Bean mung and tomato	Root promoter	Hernández-Herrera *et al.* (2016)
	Ulva lactuca	Neutral and alkaline	Bean mung and tomato	Root promoter	Hernández-Herrera *et al.* (2016)
	Sargassum liebmannii	Neutral	Jicama (*Pachyrhizus erosus* Linnaeus)	Germination promoter	Nicolás-Álvarez *et al.* (2015)
IV Gulf of Mexico	*Ulva lactuca*	Unspecific	Unspecific	Growth promoter	Garduño-Solórzano *et al.*, 2005
V Mexican Caribbean	*Hydroclathrus clathratus* (C. Agardh) M. Howe	Unspecific	Unspecific	Growth promoter	Robledo-Ramírez y Freile-Pelegrín (1998)
	Sargassum filipendula C. Agardh	Unspecific	Unspecific	Growth promoter	Robledo-Ramírez y Freile-Pelegrín (1998)
	Sargassum fluitans (Børgesen) Børgesen	Unspecific	Unspecific	Growth promoter	Robledo-Ramírez y Freile-Pelegrín (1998)
	Turbinaria tricostata E.S. Barton	Unspecific	Unspecific	Growth promoter	Robledo-Ramírez y Freile-Pelegrín (1998)
	Turbinaria turbinata (Linnaeus) Kuntze	Unspecific	Unspecific	Growth promoter	Robledo-Ramírez y Freile-Pelegrín (1998)

better use of seaweed resources and their extracts in crops. 1) Does the same raw material processed by different extraction methods lead to extracts with different characteristics? (Briceño-Domínguez *et al.*, 2014; Hernández-Herrera *et al.*, 2016). 2) How long does the effect persist after application of seaweed extracts? (Hernández-Herrera *et al.*, 2014b). 3) Is it possible to combine different extracts from different seaweeds at different concentrations for synergistic effects? (Hernández-Carmona & Di Filippo-Herrera, unpublished). It would also be interesting to study the physiological effects of specific chemical components in order to develop a second generation of seaweed products with specific plant biostimulants activity.



Figures 5a-b. Root inducer activity. a) A standard curve for root formation in mung bean plants treated with indol-3-butyric acid (IBA) at 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, and 10^{-3} concentration (M) as reference; b) IBA equivalents (M) on root formation with polysaccharide-enriched extracts obtained with neutral (N-PEE) and alkaline (A-PEE) conditions from *Ulva lactuca* Linnaeus (UL) and *Padina gymnospora* (Kützing) Sonder (PG) at concentration of 1.0 mg mL^{-1}. Values represent the mean of n = 20 seedlings, bars represent standard errors. Bar = 1 cm.

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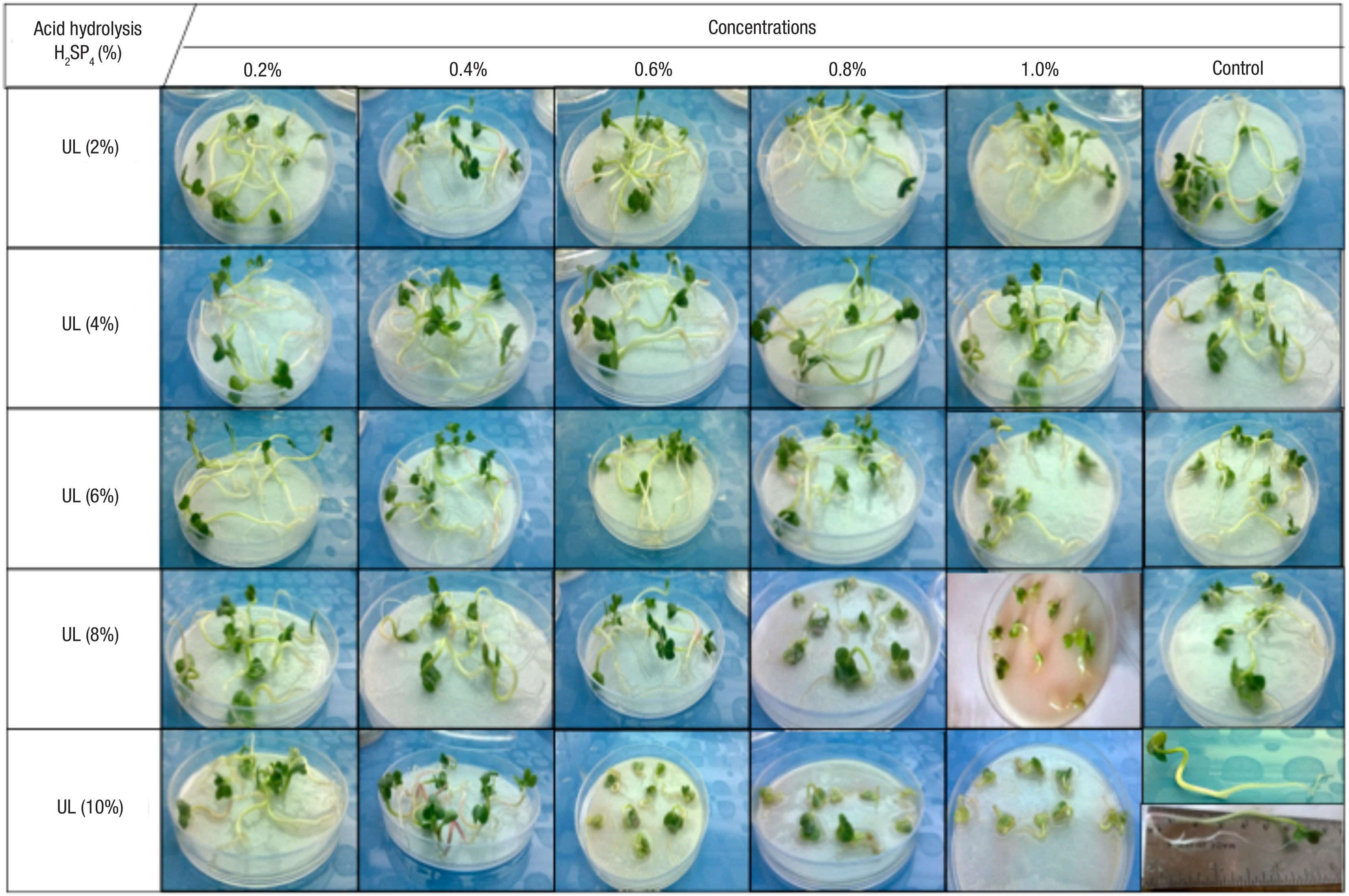

Figure 6. Effect of extracts from *Ulva lactuca* Linnaeus (UL) obtained with acid hydrolysis conditions (H_2SO_4 at 2, 4, 6, 8, and 10 %) at different concentrations (0.2, 0.4, 0.6, 0.8, and 1.0%) on red radish germinate. Best results were obtained with the treatment of UL2 at 0.2%.

REFERENCES

Aguilar-Rosas, L. E. 1982. Ocurrencia de algas cafés (Phaeophyta) en la bahía Todos Santos, Baja California. *Ciencias Marinas* 8: 25-34. Available online at: http://www.cienciasmarinas.com.mx/index.php/cmarinas/issue/view/38/showToc

Ali, N., A. Farrell., A. Ramsubhag & J. Jayaraman. 2016. The effect of *Ascophyllum nodosum* extract on the growth, yield and fruit quality of tomato grown under tropical conditions. *Journal of Applied Phycology* 28: 1353-1362. DOI:10.1007/s10811-015-0608-3

Calvillo-Unna L. A 2009. Un caso de simulación del federalismo. La ley general de pesca y acuacultura sustentables. *Alegatos - Revista Jurídica de la Universidad Autónoma Metropolitana* 71: 127-138. https://www.azc.uam.mx/publicaciones/alegatos/pdfs/64/71-08.pdf

Castellanos-Barriga, L. G., F. Santacruz-Ruvalcaba., G. Hernández-Carmona., E. Ramírez-Briones & R. M. Hernández-Herrera. 2017. Effect of seaweed liquid extracts from *Ulva lactuca* on seedling growth of mung bean (*Vigna radiata*). *Journal of Applied Phycology* 29: 2479-2488. DOI:10.1007/s10811-017-1082-x

Briceño-Domínguez, D., G. Hernández-Carmona., M. Moyo., W. Stirk & J. Van Staden. 2014. Plant growth promoting activity of seaweed liquid extracts produced from *Macrocystis pyrifera* under different pH and temperature conditions. *Journal of Applied Phycology* 26: 2203-2210. DOI:10.1007/s10811-014-0237-2

Canales-López, B. 1999. Enzimas-algas: posibilidades de su uso para estimular la producción agrícola y mejorar los suelos. *Terra* 17 (3): 271-276. Available online at: https://chapingo.mx/terra/contenido/17/3/art271-276.pdf

Craigie, J. S. 2011. Seaweed extract stimuli in plant science and agriculture. *Journal of Applied Phycology* 23: 321-335. DOI:10.1007/s10811-010-9560-4

DOF Diario Oficial de la Federación. 2012. Plan de Manejo para la Pesquería de Macroalgas en Baja California, México. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. (SAGARPA). Available online at: http://dof.gob.mx/nota_detalle_popup.php?codigo=5280840. (downloaded 14 June 2016).

Fornes, F., M Sánchez-Perales & J.L. Guadiola. 2002. Effect of a seaweed extract on the productivity of 'de Nules' Clementine mandarin and navelina orange. *Botanica Marina* 45: 486-489

García-Sahagún, M. L., A. De Luna Vega., C. Zuñiga-Campa., O. A. Bañuelos-Gutiérrez & M. Silva-Echeverría. 2014. Efecto de algas marinas en el desarrollo de *Gerberajamesonii* (Asteraceae). *e-Cucba* 2: 39-45. Available online at: http://e-cucba.cucba.udg.mx/index.php/e-Cucba/article/view/14/pdf_7

Garduño-Solórzano, G., J. L. Godínez-Ortega & M. M. Ortega. 2005. Distribución geográfica y afinidad por el sustrato de las algas verdes (Chlorophyceae) bénticas de las costas mexicanas del Golfo de México y Mar Caribe. *Boletín de la Sociedad Botánica de México* 76: 61-78. Available online at: http://www.redalyc.org/pdf/577/57707606.pdf

Gireesh, R., C. K. Haridevi & J. Salikutty. 2011. Effect of *Ulva lactuca* extract on growth and proximate composition of *Vigna unguiculata* L. Walp. *Journal of Research in Biology* 8: 624-630. Available online at: http://jresearchbiology.com/ Documents/RA0148.pdf.

González, A., J. Castro, J. Vera & A. Moenne. 2013a. Seaweed oligosaccharides stimulate plant growth by enhancing carbon and nitrogen assimilation, basal metabolism, and cell division. *Journal of Plant Growth Regulation* 32: 443-448. DOI:10.1007/s00344-012-9309-1

González, A., R. A. Contreras & A. Moenne. 2013b. Oligo-carrageenans enhance growth and contents of cellulose, essential oils and polyphenolic compounds in *Eucalyptus globulus* trees. *Molecules* 18: 8740-8751. DOI:10.3390/molecules18088740.

Gupta, S. & N. Abu-Ghannam. 2011. Recent developments in the application of seaweeds or seaweed extracts as a means for enhancing the safety and quality attributes of foods. *Innovative Food Science & Emerging Technologies* 12: 600-609. DOI:10.1016/j.ifset.2011.07.004

Hernández-Alarcón, I. 2014. Evaluación de un extracto alcalino del alga *Macrocystis pyrifera* (L.) C. Agardh, sobre el crecimiento de vegetales terrestres. Tesis de Licenciatura en Biología Marina. Universidad Autónoma de Baja California Sur. México. 47 p.

Hernández-Garibay, E., J. Guardado-Puentes., J. Bautista-Alcantar & R. Reyes-Tisnado. 2006. Macroalgas del Océano Pacífico. *In:* Cuellar J. (Ed). *Sustentabilidad y Pesca Responsable en México*. Instituto Nacional de la Pesca, SAGARPA. pp. 235-244.

Hernández-Herrera, R. M., F. Santacruz-Ruvalcaba., M. A. Ruiz-López., J. Norrie & G. Hernández-Carmona. 2014a. Effect of liquid seaweed extracts on growth of tomato seedlings (*Solanum lycopersicum* L.). *Journal of Applied Phycology* 26: 619-628. DOI:10.1007/s10811-013-0078-4

Hernández-Herrera, R. M., G. Virgen-Calleros., M. A. Ruiz-López., J. Zañudo-Hernández., J. P. Délano-Frier & C. Sánchez-Hernández. 2014b. Extracts from green and brown seaweeds protect tomato (*Solanum lycopersicum*) against the necrotrophic fungus *Alternaria solani*. *Journal of Applied Phycology* 26: 1607-1614. DOI:10.1007/s10811-013-0193-2

Hernández-Herrera, R. M., F. Santacruz-Ruvalcaba, J. Zañudo-Hernández & G. Hernández-Carmona. 2016. Activity of seaweed extracts and polysaccharide-enriched extracts from *Ulva lactuca* and *Padina gymnospora* as growth promoters of tomato and mung bean plants. *Journal of Applied Phycology* 28: 2549-2560. DOI:10.1007/s10811-015-0781-4

Hong, D. D., H. M. Hien & P. N. Son. 2007. Seaweeds from Vietnam used for functional food, medicine and biofertilizer. *Journal of Applied Phycology* 19: 817-826. DOI:10.1007/s10811-007-9228-x

Jayaraj, J., A. Wan., M. Rahman & Z. K. Punja. 2008. Seaweed extract reduces foliar fungal diseases on carrot. *Crop Protection* 10: 1360-1366. DOI:10.1016/j.cropro.2008.05.005

Jayaraman, J & N. Ali. 2015. Use of seaweed extracts for disease management of vegetable crops. *In:* Ganesan S., Vadivel K., Jayaraman J. (Eds.). *Sustainable Crop Disease Management using Natural Products*. Oxfordshire, UK, CABI, pp. 160-183. DOI:10.1079/9781780643236.0160

Khan, W., U. P. Rayirath., S. Subramanian., M. N. Jithesh., P. Rayorath., D. M. Hodges., A. T. Critchley., D. Laporte., J. Vera., N. P. Chandía., E. A. Zúñiga., B. Matsuhiro & A. Moenne. 2007. Structurally unrelated algal oligosaccharides differentially stimulate growth and defense against tobacco mosaic virus in tobacco plants. *Journal of Applied Phycology* 19: 79-88. DOI:10.1007/s10811-006-9114-y

Martínez-Morales, J. S. 2015. Evaluación de extractos de algas marinas como promotores de crecimiento en cultivos terrestres. Tesis de Maestría, CICIMAR-IPN, México. 50 p.

Mattner, S. W., D. Wite., D. A. Riches., I. J. Porter & T. Arioli. 2013. The effect of kelp extract on seedling establishment of broccoli on contrasting soil types in southern Victoria, Australia. *Biological Agriculture & Horticulture* 29: 258-270. DOI:10.1080/01448765.2013.830276

Nicolás-Álvarez, D. E., L. E. Mateo-Cid., A.C. Mendoza-González., M. Gutiérrez-Ladrón De Guevara & A. Reyes-Chaparro. 2014. Utilization of Seaweed *Sargassum liebmannii* extract as a stimulant of germination of *Pachyrhizus erosus*. *Journal of Chemical, Biological and Physical Sciences* (JCBSC) 4: 56-61.

Ortega, M. M. 1987. Doce años de ficología en México (971-1983). *In*: Gómez Aguirre. S. y V. Arenas Fuentes (Eds.). Contribuciones en hidrobiología. Memoria de la Reunión Alejandro Villalobos (24 al 26 de octubre de 1983). Universidad Nacional Autónoma de México. México, D.F. pp. 155-186.

Osorio-Tafall, B. F. 1946. Anotaciones sobre algunos aspectos de la hidrobiología Mexicana. *Revista de la Sociedad Mexicana de Historia Natural* 7:139-165. Available online at: http://repositorio.fciencias.unam.mx:8080/jspui/bitstream/11154/142549/1/7VAnotacionesSobre.pdf

Pacheco-Ruíz, I. & J. A. Zertuche-González. 1996. The commercially valuable seaweeds of the Gulf of California. *Botánica Marina* 39: 201-206. DOI:10.1515/botm.1996.39.1-6.201

Pedroche, F. F & A. Sentíes. 2003. Mexican marine phycology. Diversity and problems. *Hidrobiológica* 13: 23-32. Available online at: http://www.scielo.org.mx/pdf/hbio/v13n1/v13n1a3.pdf

Rayorath, P., M. N. Jithesh., A. Farid., W. Khan., R. Palanisamy., S. D. Hankins., A. T. Critchley & B. Prithiviraj. 2008. Rapid bioassays to evaluate the plant growth promoting activity of *Ascophyllum nodosum* (L.) Le Jol. using a model plant, *Arabidopsis thaliana* (L.) Heynh. *Journal of Applied Phycology* 20: 423-429. DOI:10.1007/s10811-007-9280-6

Rebours, C., E. Marinho-Soriano, J. A. Zertuche-González, L. Hayashi, J. A. Vásquez, P. Kradolfer, G. Soriano, R. Ugarte, M. H. Abreu, I. Bay-Larsen, G. Hovelsrud, R. Rødven & D. Robledo. 2014. Seaweeds: an opportunity for wealth and sustainable livelihoods for coastal communities. *Journal of Applied Phycology* 26: 1939-1951. DOI:10.1007/s10811-014-0304-8

Rengasamy, K. R. R., M. G. Kulkarni, W. A. Stirk & J. Van Staden. 2015a Eckol a new plant growth stimulant from the brown seaweed *Ecklonia maxima*. *Journal of Applied Phycology* 27: 581-587. DOI:10.1007/s10811-014-0337-z

Rengasamy, K. R. R., M. G. Kulkarni., W. A. Stirk & J. Van Staden. 2015b. Eckol improves growth, enzyme activities, and secondary metabolite content in maize (*Zea mays* cv. Border King). *Journal of Plant Growth Regulation* 34: 410-416. DOI:10.1007/s00344-015-9479-8

Robledo, D., E. Gasca-Leyva & J. Fraga. 2013. Social and economic dimensions of carrageenan seaweed farming in Mexico. *In*: Valderrama D., Cai J., Hishamunda N., Ridler N. (Eds.). Social and Economic Dimensions of Carrageenan Seaweed Farming. *Fisheries and Aquaculture Technical Paper* No. 580. Rome, FAO, pp. 185-204.

Robledo, D. & W. Townsend. 2006. Seaweed and mangroves: improving environmental practices in coastal communities to secure sustainable livelihoods. *In:* Breton Y., D. Brown, E.B. Davey, M. Haughton M & L. Ovares (Eds). Coastal Resource Management in the Wider Caribbean: Resilience, Adaptation, and Community Diversity. Kingston, Jamaica, Ian Randle Publishers; Ottawa, International Development Research Centre 190 p. Available online at: https://www.researchgate.net/publication/256183984_SEAWEEDS_AND_MANGROVES_IMPROVING_ENVIRONMENTAL_PRACTICES_IN_COASTAL_COMMUNITIES_OF_MEXICO_AND_JAMAICA

Robledo-Ramírez, D. & Y. Freile-Pelegrín. 1998. Macroflora marina de interés económico de las costas de Yucatán. *In:* Benítez H., E. Vega, A. Peña & S. Ávila. (Eds.). *Aspectos Económicos Sobre la Biodiversidad de México*. México, CONABIO-SEMARNAP, pp. 167-179.

Rothäusler, E., L. Gutow & M. Thiel. 2012. Floating seaweeds and their communities. *In:* C. Wiencke & K. Bischof (Eds.). *Seaweed Biology - Novel Insights into Ecophysiology, Ecology and Utilization*, Ecological Studies 219, Berlin Heidelberg, Springer, 21 p. DOI:10.1007/978-3-642-28451-9_17

SAGARPA (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación). 2012. Reglas de Operación de los Programas de SAGARPA. *DOF* del 30 November 2012. Available online at: http://inapesca.gob.mx/portal/documentos/publicaciones/30112012%20SAGARPA.pdf (Downloaded 10 May 2016).

Satish, L., S. A. Ceasar, J. Shilpha, S. A. Rency, P. Rathinapriya & M. Ramesh. 2015a. Direct plant regeneration from in vitro-derived shoot apical meristems of finger millet (*Eleusine coracana* (L.) Gaertn.). *In Vitro Cellular & Devolpmental Biology –Plant* 51: 192-200. DOI:10.1007/s11627-015-9672-2

Satish, L., R. Rameshkumar, P. Rathinapriya, S. Pandian, A. S. Rency, T. Sunitha & M. Ramesh. 2015b. Effect of seaweed liquid extracts and plant growth regulators on in vitro mass propagation of brinjal (*Solanum melongena* L.) through hypocotyl and leaf disc explants. *Journal of Applied Phycology* 27: 993-1002. DOI:10.1007/s10811-014-0375-6

Sharma, H. S., C. Fleming, C. Selby, J. R. Rao & T. Martin. 2014. Plant biostimulants: a review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. *Journal of Applied Phycology* 26: 465-490. DOI:10.1007/s10811-013-0101-9

Sunarpi, A., R. Jupri, N. I. Kurnianingsih & A. Nikmatullah. 2010. Effect of seaweed extracts on growth and yield of rice plants. *Bioscience* 2 (2): 73-77.DOI:10.13057/nusbiosci/n020204

Thirumaran, G., M. Arumugam, R. Arumugam & P. Anantharaman. 2009. Effect of seaweed liquid fertilizer on growth and pigment concentration of *Abelmoschus esculentus* (l) Medikus. *American-Eurasian Journal of Agronomy* 2 (2): 57-66. Available online at: https://www.idosi.org/aeja/2(2)09/3.pdf

Turan, M & C. Köse. 2004. Seaweed extracts improve copper uptake of grapevine. *Acta Agriculturae Scandinavica*, Section B - Soil & Plant Science 54: 213-220. DOI:10.1080/09064710410030311

Vera, J., J. Castro, A. González, H. Barrientos, B. Matsuhiro, P. Arce, G. Zúñiga & A. Moenne. 2011a. Long term protection against tobacco mosaic virus induced by the marine alga oligo-sulphatedgalactan Poly-Ga in tobacco plants. *Molecular Plant Pathology* 12: 437-447. DOI:10.1111/j.1364-3703.2010.00685.x

Vera, J., J. Castro, A. González & A. Moenne. 2011b. Seaweed polysaccharides and derived oligosaccharides stimulate defense responses and protection against pathogens in plants. *Marine Drugs* 9: 2514-2525. DOI:10.13057/nusbiosci/n020204

Villarreal-Sánchez, J. A., A. Llyina, L. P. Mendez-Jiménez, V. Robledo-Torres, R. Rodríguez-Herrera, B. Canales-López & J. Rodríguez-Martínez. 2003. Isolation of microbial groups from a seaweed extract and comparison of their effects on a growth of pepper culture (*Capsicum annuum* L.). M*oscow University Chemistry Bulletin* 44: 92-96. Available online at: http://www.chem.msu.su/rus/vmgu/031/92.pdf

Vinoth, S., P. Gurusaravanan & N. Jayabalan. 2012a. Effect of seaweed extracts and plant growth regulators on high-frequency *in vitro* mass propagation of *Lycopersicon esculentum* L (tomato) through double cotyledonary nodal explant. *Journal of Applied Phycology* 24:1329-1337. DOI:10.1007/s10811-011-9717-9

Vinoth, S., P. Gurusaravanan & N. Jayabalan. 2012b. Erratum to: effect of seaweed extracts and plant growth regulators on high-frequency in vitro mass propagation of *Lycopersicon esculentum* L (tomato) through double cotyledonary nodal explant. *Journal of Applied Phycology* 24: 1339-1340. DOI:10.1007/s10811-011-9748-2

Vinoth, S., P. Gurusaravanan & N. Jayabalan. 2014. Optimization of somatic embryogenesis protocol in *Lycopersicon esculentum* L. using plant growth regulators and seaweed extracts. *Journal of Applied Phycology* 26: 1527-1537. DOI:10.1007/s10811-013-0151-z

Zertuche-González, J. A., M. Sánchez-Barredo, J. M. Guzmán-Calderón & Z. Altamirano-Gómez. 2014. *Eisenia arborea* J.E. Areschoug as abalone diet on an IMTA farm in Baja California, México. *Journal of Applied Phycology* 26 (2): 957-960. DOI:10.1007/s10811-013-0138-9

Zamani, A., S. Khorasaninejad & B. Kashefi. 2013. The importance role of seaweeds of some characters of plant. *International Journal of Agriculture and Crop Sciences* 5 (16): 1789-1793.

Zhang, X & R. E. Schmidt. 2000. Hormone-containing products' impact on antioxidant status of tall fescue and creeping bent grass subjected to drought. *Crop Science* 40: 1344-1349. DOI:10.2135/cropsci2000.4051344x