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# *Bryopsis* spp.: Generalities, Chemical and Biological Activities

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**ABSTRACT**

*Bryopsis* spp, is a marine green algae distributed in tropical regions of worldwide which have been few studied a level of their chemical constitution and evaluation of properties of bioactive metabolites and derivatives with a high potential pharmacological in treatment of possible disease related with viral, fungi and bacterial diseases. Relevant information was selected from scientific journals, books and electronic reports employed database including PubMed, Science Direct, Scielo and Google Scholar. This review describe different aspects of the *Bryopsis* spp. such as general characteristics, some species found in tropical regions included in Colombia, metabolites derivatives and finally roles in the pharmacological activity with promissory application in drug discovery and therapies related with antitumoral, antioxidant, antimicrobial, antiviral, anti-larvicidal, anticoagulant and antileishmanial. This review offers a new vision of the knowledge about of studies of product naturals and specifically in the investigations referred to *Bryopsis* spp. may be of great significance for the discovery of drugs for future treatments; thus may be generated new literature of natural elements and its potential drug target.

**Key words:** *Bryopsis* spp, Activity, Algae, Metabolites.

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## INTRODUCTION

For several decades it has been shown that marine organisms are an important and representative source of new potentially bioactive metabolites, such as carotenoids, vitamins, minerals, carbohydrates, peptides and phenolic compounds.[1-4] The efficiency of "classical" antibiotics has decreased significantly. New drugs to fight MDR strains are urgently needed. Bacteria hold much promise as a source of unusual bioactive metabolites. However, the potential of marine bacteria, except for Actinomycetes and Cyanobacteria, has been largely underexplored. In the past two decades, the structures of several antimicrobial compounds have been elucidated in marine Proteobacteria. Of these compounds, polyketides (PKs According to the presence of pigments, can be classified into: Chlorophyceae (green algae), Phaeophyceae (brown algae) and Rhodophyceae (red algae).[5-8] Macroalgae as *Bryopsis* sp. are abundant and potentially renewable resources that are currently being explored as a source of compounds for pharmaceutical and nutraceutical industry.[9-12] Algae structurally contain a succession of components, the most representative are fiber, proteins, minerals, vitamins, antioxidants and polyunsaturated fatty acids (PUFA), with low caloric.[6,13-17] The several diversity of algae combined with the extreme conditions of salinity, light and temperature in the habitat of some species, explain considerably the interest in isolating primary and secondary metabolites produced by these organisms.[4] Studies on the activity of compounds present in marine algae have shown potential effects as elements antioxidant, antimicrobial, anti-inflammatory, anticoagulant, antiprotozoal and antitumor activity.[10,18-23] However, studies that demonstrate the presence of bioactive metabolites in green algae as *Bryopsis* spp are limited. Therefore, it is of great interest the approach of investigative reports to the determination of the composition, functional role and activities associated with the content of metabolites present in this type of organisms. Thus, a conceptual approach has been made with respect to group of green algae as *Bryopsis* genus, which were emphasized in the theoretical characterization, generalities, constituent and related active compounds and a detailed approach to the most important investigations associated with the pharmacological activity of this type of algae. Which constitute fundamental elements for its experimental, technical and theoretical exploration and application.

## METHODS

The study of the literature review was carried out by searching on the databases including PubMed, Science Direct, Scielo and Google Scholar for studies of the biological activities of *Bryopsis* spp. All Spanish and English-language articles published between 2000 and 2018 were searched using the terms '*Bryopsis* spp.', 'green algae', 'activity'. The list of references of all the relevant articles was also studied and reviews related to the subject.

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## RESULTS AND DISCUSSION

### Generalities of *Bryopsis* spp.

The *Bryopsis* genus constitutes a group of siphoned marine algae of 1-20 cm length feathery-like that have been intensively studied under conditions related to its life cycle and widely distributed from tropical and temperate seas.[24,25]Chlorophyta Frequently are adhered to rocks and other seaweeds, principally in the intertidal to subtidal zone. Alike, 200 species been described, which about 55 are recognized.[26]

Almost all well-known members genus present heteromorphic digestic cycles, with alternation of gametophytes and sporophytes morphologically different.[27] In this genus gametophytes are characterized by producing biflagellate gametes that are discharged through gametangial papillae, while sporophytes usually produce zoospores, which are released by rupture and gelatinization of the sporangial walls.[25] Likewise, is notably found the presence of single nucleus in the microthallus called primary nucleus localized in the rhizoids of the thallus, have been evidenced that microthallus is originate due zygote with primary nucleus diploid and have evidenced a process of meiosis generated during sporogenesis and microthallus haploid. Similarly, have demonstrated that species of *Bryopsis* as *B. plumosa* are able of divide in form mitotic by vegetative tallus propagation.[28]

For another hand, have been described a symbiotic behavior within *Bryopsis* and bacterial endophytes which have observed intracellularly in cytoplasm and vacuolar regions in structures as gametes. These phenomenous demonstrate a relationship between the macroalga and bacterial communities modifying structural and functional of this type of algae, some have been implicated in the biotransformation, degradation and modification of nutrients in marine organisms associated.[29-31] Thus, species such as Arcobacter, Bacteroidetes, Labrenzia, Flavobacteriaceae, Mycoplasma, Phyllobacteriaceae and Xanthomonadaceae species have evidenced a symbiotic process which have revealed by sequencing studies.[30,32]

In the Table 1 are shown characteristic, localization and habitats most important of species of community of marine algaes of genus *Bryopsis* as *Bryopsis pennata* Lamouroux 1809, *Bryopsis pennata* var. secunda (Harvey) Collins and Hervey, *Bryopsis plumose* C. Agardh, 1823 and *Bryopsis hypnoides* J.V. Lamouroux are species most frequents in worldwide, characterized by a habitat tropical climates and able to survive in cosmopolitan environmental. Figure 1.

### Metabolites in *Bryopsis* spp. and chemical composition

The varied constitution of metabolites present in marine algae has been a research development for the functional role of possible promissory. Particularly from the study of the group of green algae of the *Bryopsis* spp genus. It's have allowed identification of a number of metabolites involved in different biological activities.

### Carbohydrates

Have been determinate monosaccharide's including arabinose, galactose, glucose, mannose, xylose and rhamnose. (Figure 2). Likewise, cell wall contain polysaccharides rich in galactans as 3-linked β-D-galactopyranose (β-D-Gal) residues, the (1→4)-linked β-D-mannan, (1→3)-linked β-D-xylan, sulfated xyloarabinogalactans and sulfated pyruvylated galactans, cellulose and pectin. [3,33-39] (Figure 3).

### Peptides and proteins

Peptides as kahalalide F (KF), Figure 4 iso-kahalalide F (isoKF), kahalalide A, B, C, D, E, F, G, K, O, P, V, W, X, Y; have been isolated from the mollusk *Elysia rufescens* and its diet alga *B. pennata* or obtained by synthesis chemical, which are associated a multiples biological activities such as antiviral, antimicrobial and antitumorals.[9,40-45] Similarly, have been described protein as protein-complexes as chlorophyll-protein, cytochrome B6-F complex, chloroplast EF-Tu, involved in electron transport in the chloroplast thylakoid that take part in oxygenic photosynthesis. Lectins including bryohealin, BPL-3, BPL-4, involved at the aggregation and regeneration cell during protoplast formation in B. plumose.[42]

### Sterols and terpenoid compound

Is founded widely content of steryl esters, alkyl esters, triacylglycerols, free fatty acids, monogalactosyldiacylglycerols, digalactosyldiacylglycerols, diacylglycerophosphoglycerols, diacylglycerophosphoethanolamine cholesterol derivatives as cholesta-5,20,24-trien-3-ol, ergo sterol or ergosta-5,7,22-trien-3-ol,[46] lumisterol, lich sterol, ergo sterol B1, 3-hexyl-1,2-dithiepan-5-one, 2,3-epoxy-1-phytanol, β-sit sterol, clionasterol, clerosterol, dihidrobrassicasterol, 24-metilecasterol, isofocusterol and desmesterol.[47-50] Terpenoid compounds and carotenoids compounds (9-cis-α-carotene, xanthophylls, siphonaxanthin, siphoning, ε-carotene).

### Minerals

Also, have been described mineral salts and micro nutrients have including calcium, phosphorus, sodium, potassium, magnesium, cupper, iron, zinc.[51]

### Biological Activities

### Antioxidant Activity

The antioxidant activity and effect of uptake of free radicals by use of extracts of microalgae from the Chlorophyceae species, as established by Ishakani *et al*. among the report of 32 tested species, it was recorded that *B. plumosa* consistently presented a capturing activity of 10.33 ± 1.38 mM equivalents of ascorbic acid/g DW and a significant polyphenol content of 21.17 ± 1.15 mg/g DW. The authors established the existence of a relationship between the polyphenol content and free radical scavenging activity,[52] which was dependent on the wide range of distribution and positioning of the species coasts and a possible incidence between the degree of radiation penetration UV in different areas, which can be established in the variable mechanisms against oxidative stress.[53] Zhang *et al*. demonstrated that sulphated polysaccharides extracted of *B. plumosa* shown favourable antioxidant activity including effects as scavenging effects of superoxide and hydroxyl radicals and reducing power[54-56] Song *et al*. have studied the effect of modified polysaccharides with sulphate groups from *B. plumosa* and its relationship with free radical scavenger and inhibitory effect of superoxide radicals and DPPH, established by assays *in vitro* models against superoxide radicals and significant DPPH, throwing $IC_{50}$ values of 9.2 μg mL-1 and 1.7mg mL-1.[57,58] Additionally, a remarkable effect of sulphated polysaccharides in the reducing power was demonstrated, which leads to the use of these species as promising tools for their use as ingredients of health care or as a preventive and functional agent.[59,60] Similar studies established by Chejara *et al*. determined the activity of crude extracts in methanol, ethyl acetate and chloroform from *B. plumosa* (Hudson), in which a consistent antioxidant activity was found in relation to the superoxide radical scavenging activity and a relationship with the reducing power, as well as the capacity to reduce $Fe^{3+}$. Likewise, it was demonstrated that the extracts from methanol showed a better antioxidant efficiency and a reducing power that showed a comparable activity when compared with BHT at concentrations of 0.5 mg/mL. Has been established activities may be due to metabolites such as polyphenols, steroids, terpenoids and saponins.[44]

### Antimicrobial Activity

Manilal *et al*. evaluated 47 species of marine organisms, including *B. pennata* in pathogenic strains in humans and shrimp. Antibacterial activity and

**Table 1: Principal species of *Bryopsis* spp. algae.**

| Specie | Description | Environmental | Reference |
|---|---|---|---|
| *Bryopsis pennata* J.V.Lamouroux<br><br>*(B. pennata* J.V.Lamouroux, 1809) | Thallus most commonly of erect, feather-like uniaxial fronds from a rhizoidal holdfast; height about 2 cm. to occasionally over 40 cm. Alga constructed of coenocytic filaments or siphons. Siphon walls and sporophytic phase enriched with mannan, cellulose and xylan. One type of plastid occurs (homoplastic), which contains a pyrenoid. Asexual reproduction include fragmentation, aplanospores and regeneration from extruded protoplasts. Sexual reproduction by biflagellated anisogametes produced in unspecialized branchlets (pinnae) segregated from remainder of frond by basal membrane. | General distribution in polar to tropical latitudes, temperatures from at least 5 to 27°C. Vertically extends from mid littoral to at least -5 m.<br>Europe: Adriatic Sea, Balearic Islands, Greece, Italy, Portugal, Spain.<br>America: North America, Mexico, Costa Rica, Belize, Curaçao, Trinidad and Tobago, Brazil, Chile, Colombia, Guyana, Venezuela, Uruguay.<br>Africa: Angola, Benin, Cameroon, Côte d'Ivoire, Egypt, Equatorial Guinea, Eritrea, Gabon, Gambia, Ghana, Nigeria, Senegal, Sierra Leone.<br>Asia: China, Japan, Korea, Indonesia Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam. | [99-103] |
| *Bryopsis pennata* var. secunda (Harvey) Collins and Hervey | Present a single, coenocytic tubular cell that grows from the apex. Transverse walls are absent. There is a creeping system of rhizoids erect with axes of 5-7 cm (length). This main axis evidence opposite pinnate branches. Certain branches are separated from the main axis by the formation of cross walls to be transformed into gametangia. | Asia: Japan, China, Taiwan<br>America: Mexico, Cuba, Martinique, Brazil, Venezuela.<br>Africa: Equatorial Guinea, Ghana, Mauritius, São Tomé and Príncipe, Tanzania.<br>Ocenia: Australia and New Zealand. | [104] |
| *Bryopsis plumose*<br><br>(*Bryopsis plumosa* C. Agardh, 1823) | Its characterized by has distichous branches with a thallus small and erect, able to grow up to 10 cm long. Additionally, the microthallus is composed of a rhizoid region with short laterals and a more or less upright part with elongate filaments. The microthallus reaches its final length (2.5-3 cm). | It can growth in warm and temperate seas. Common in sheltered to moderate water movement localities; eulittoral and uppermost sublittoral.<br>Asia: Taiwan<br>Europe: Adriatic Sea, Balearic Islands, Baltic sea, Black sea, Britain, Bulgaria, Faroe Islands, France, Greece, Italy, Malta, Portugal, Spain, Turkey.<br>America: North America, Mexico, Panama, Barbados, Cuba, Martinique, Trinidad, Trinidad and Tobago, Argentina, Brazil, Chile, Colombia, Peru, Venezuela.<br>Africa: Algeria, Angola, Egypt, Gambia, Ghana, Kenya, Morocco, Senegal, Sierra Leone. | [24,28] |
| *Bryopsis hypnoides* J.V. Lamouroux | Filamentous tufts, 10 cm tall, branching irregular and scattered. Primary axes branched and fronds of minor diameter with each division; branchlets irregular and undifferentiated. Apices rounded. Rhizoidal system fibrous with color dull or dark green. | Common near freshwater and nutrient rich outputs. Attaches to hard substrates such as basalt, rocks, or rubble. Forms delicate fronds which move with currents.<br>Europe: Adriatic Sea, Baltic sea, Black sea, Britain, Bulgaria, France, Greece, Ireland, Italy, Portugal, Romania, Spain, Turkey.<br>America: North America, El Salvador, Mexico, Panama, Bahamas, Cuba, Martinique, Trinidad and Tobago, Brazil, Chile, Galápagos Islands, Uruguay, Venezuela.<br>Africa: Algeria, Egypt, Eritrea, Kenya, Madagascar, Mauritius, Mediterranean Sea, Morocco<br>Asia: China, Japan, Korea, South China Sea, Singapore, Vietnam.<br>Others: Australia and New Zealand. | [100,105,106] |

sensitivity were reported in the presence of methanol extracts, inducing the appearance of inhibition of *V. parahaemolyticus* and *V. vulnificus* strains.[8,61] six type cultures (Mi- crobial Type Culture Collection, MTCC Likewise, Puglisi *et al*. reported potential and selective effects of antimicrobial activity of algae extracts from *B. pennata*, an antimicrobial effectivity against strains of *L. thalassiae*, *D. salina*, *H. spinosa*, *S. aggregatum*, *P. bacteriolytica*.[62] Salvador *et al*. studied the antifungal and antibacterial activity of around 82 marine macroalgae from Iberian Peninsula, within the evaluated group it was reported that the extracts of *B. muscosa* J.V. Lamouroux and *B. corymbosa* J. Agardh, showed high values of inhibition in spectrum of action against Gram positive and Gram negative bacteria, as well as antifungal activity against yeast strains, coincident with another author´s where evidenced the KF and congeners such as kahalalide R shown antifungal activity against *Candida albicans*, *Cryptococcus neoformans*, *Mycobacterium intracellulare*, *Aspergillus fumigates*, *Cladosporium herbarum* and *C. cucumerinum*.[1,63,64] Shanmughapriya *et al*. evaluated ethanol extracts and fractions based at the methanol/toluene system (3:1) from *B. plumosa*. However, no significant antimicrobial

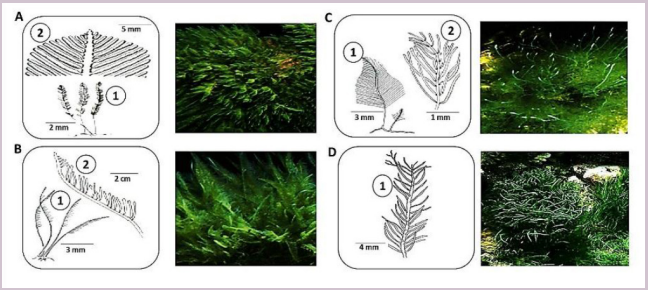

**Figure 1:** Predominant species of *Bryopsis* sp. A. *B. pennata*. B. *B. pennata* var secunda C. *B. plumosa*. D. *B. hypnoides* J.V.Lamouroux. 1 y 2. A general view of branches found in its habitat. Modificated de Scullion and Masterton (2000). *Bryopsis hypnoides* J.V.Lamouroux Adaptated of Linda Preskit. Branching pattern of *B. hypnoides* J.V.Lamouroux (Abbott and Hollenberg 1976, p. 112).

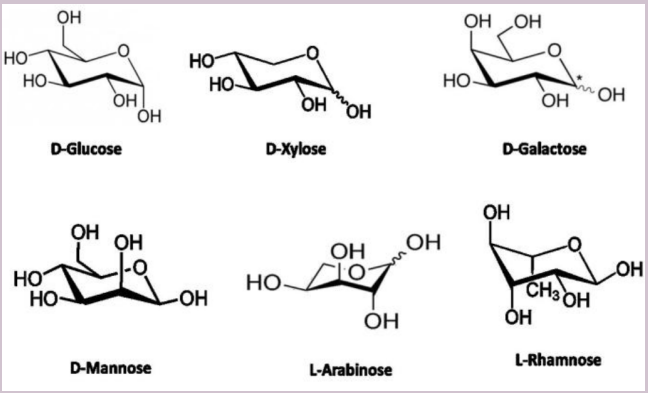


**Figure 2:** Monosaccharide's identified in *Bryopsis* spp.

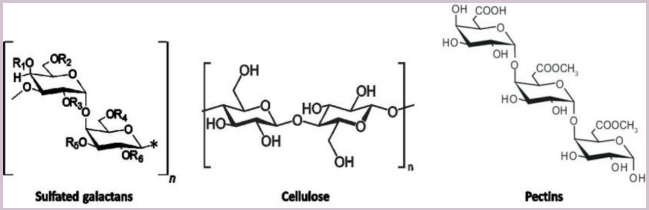


**Figure 3:** Polysaccharides in *Bryopsis* spp algae.

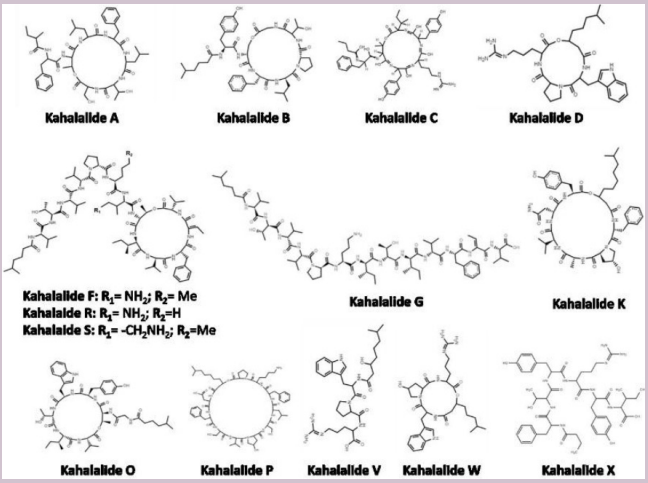


**Figure 4:** Peptides obtained of the metabolism of mollusk *Elysia* spp. product of diet of *Bryopsis* spp. and synthetic compounds.

activity against multiresistant bacterial pathogens and *C. albicans* was reported.[65] El Sayed *et al*. evidenced *in vitro* activity of kahalalide A and F against *Mycobacterium tuberculosis*.[11,66,67] KF is responsible for the antimicrobial activity can be found in macroalgae of *Bryopsis* spp.[7] Similarly, Han *et al*. indicated that extracts of *B. plumosa* showed no antimicrobial activity against Gram-positive strains such as *E. faecalis* KCTC 3206; *S. aureus*, *S. aureus* KCTC 1927 and *E. hirae* KCTC 3616 and for Gram negative bacteria (*E. coli* KCTC 11169).[68-70] Dmitrenok *et al*. in extracts of *Bryopsis* spp. and purified molecules as kahalalide P and Q have been demonstrated antimicrobial activity towards marine bacterium such as *Ruegeria atlantica*.[71]kahalalides P (1 For another hand, have evaluated antimicrobial activity of *B. pennata* against marine micro-organisms including the pathogenic as *Lindra thalassiae*, *Dendryphiella salina*, *Halophytophthora spinosa*, *Schizochytrium aggregatum* and the pathogenic bacterium *Pseudoaltermonas bacteriolytica*, which have shown inhibition the growth of all micro-organisms.[72] Agbaje-Daniels *et al*. were carried out the evaluation of extracts of *B. pennata* showed inhibitory activities against strain of *S. pullorum*, *S. enterica* and *M. morganii* with inhibitory zones of 12 mm, 7 mm and 14 mm, evidencing higher potentials against resistant strains of bacteria and discovery of new drug obtained of marine enviromentals.[73]

## Antilarvicidal and repellent Activity

Ahmad *et al*. established properties against of development of *Aedes aegypti* and *Aedes albopictus* larvae's employing methanolic extracts of *B. pennata*, which was demonstrated larvicidal activity against *A. aegypti*, around $LC_{50}$ value: 156.97 µg/mL and *A. albopictus* with $LC_{50}$ value: 177.50 µg/mL. Larvae adults showed signs of intoxication, such as restless movement, tremor, paralysis and followed by eventual death, after exposure of the extract.[74] Equally, Yu *et al*. evidenced larvicidal activity of methanolic and chloroformic extracts of *B. pennata* exhibited the strongest larvicidal activity with $LC_{50}$ value: 82.55 mg/mL, equally with methanol extract of *B. pennata* $LC_{50}$ value: 160.07 mg/mL. Likewise, it shown that larvae treated with extracts of *B. pennata* had celular alteration of the midgut epithelium. It demonstrated morphological changes and aberrations in the anal papillae and terminal spiracles.[75] Likewise, another studies established by Yu *et al*. it showed larvicidal potential of chloroform extract when exhibited strong toxic effect against *A. aegypti* ($LC_{50}$ value: 4.7 µg/mL) and *A. albopictus* ($LC_{50}$ value: 5.3 µg/mL). Conversely, the author's evaluated promissory methanol extracts, which shown strong repellent effect against oviposition against *A. aegypti*.[76]

## Antiviral Activity

Hamann and Scheuer, isolated from the mollusk *E. rufescens* depsipeptide called KF, obtained from the diet rich in the alga B. *pennata*, which in *in vitro* tests has been an antiviral activity against the herpes simplex virus II (HSV II) with a reduction of 95% at concentration of 0,5 µg/mL in mink lung cells.[77,78] Similarly, its molecule has been demonstrated effectiveness in report of studies with respect anti-HIV activity in clinical trial.[40]

### Antitumoral Activity

The cyclic depsipeptide Kahalalide F was originally isolated from mollusk *E. rufescenes* as product diet.[79] In *B. pennata* and the sacoglossan mollusk *E. rufescens*, which have been identifying about most 10 cyclic depsipeptides including kahalalides A, E, G, J, isoKF, K, O, P, Q, S, R, W, Y, V; isolated from the green alga *B. pennata* or metabolism of herbivorous marine mollusk *E. rufescens*, *E. ornata* and *E. grandifolia*.[79-82] It´s have been demonstrated as mechanism of action associated to KF and isoKF can induce apoptosis with function of lysosome membrane in target cell and DNA-synthesis inhibition; thus, in studies realized by Wang *et al*. KF and isoKF have evidencing significant *in vitro* and *in vivo* antitumor activity against various cell lines including H125, MCF-7, LNCaP, MDA-235, Hep-G2, HCT-116, human ovarian OVCAR5U, 251N and PANC-1.[17,83] Gao *et al*. have determinate sensibility to KF in human cell lines from breast including SKBR3, BT474 and MCF7, non–small-cell lung such as H460, A549, SW1573 and H292 and hepatic cell line as Skhep1, HepG2 and Hep3B;[87-90] where KF is associated blocked the epidermal growth factor receptor (ErbB family) and have identified ErbB3 and PI3K-Akt as principal determinants of the cytotoxic activity.[80,91] Likewise, Horgen *et al*. have been isolated kahalalide O from the sacoglossan *E. ornata* and its algal diet *Bryopsis* spp., demonstrated that KF present potential anticancer drug; nevertheless, not showed active in P-388, A549, HT29 and MEL28 cancer cell lines *in vitro*.[56,92] Equally, has been described cyclic depsipeptides kahalalides P and kahalalides Q with activity inhibitory of the HL-60 cell lines.[71] Which have showed 40 and 30% de inhibitory activity in HL-60 cancer cell lines. However, another of study compound is kahalalide O with low significantly cytotoxic, evidencing poor inhibit the growth of P-388, human lung carcinoma, human colon carcinoma and human melanoma cancer cell lines *in vitro*.[92] For another hand, Cruz *et al*. evidenced the activity of KF at cytotoxicity assay obtaining yielded $LC_{50}$ values of 10.23 ± 1.02 and 25.80 ± 0.11 μM in peritoneal macrophages and bovine aortic endothelial cells (BAEC) respectively.[93] Kan *et al*. were isolated from the green alga *Bryopsis* sp. an analogue structure as kahalalide K characterized by shown a 3-hydroxy-9-methyl- decanoic acid moiety that similarly identified in kahalalides E, H and J; however, kahalalide K showed no cytotoxicity against neuroblastoma cells at concentration of 100 μg/mL.[94,95]

### Anticoagulant Activity

It´s have been evidenced properties anticoagulants of green algaes of genus *Bryopsis* sp., according of established by Ciancia *et al*. which indicated that polysaccharides sulphated of *B. maxima* enriched in glucose and xylose demonstrated a considerable presence of the anticoagulant effect.[33,35,37] Equally, Shanmugam *et al*. evaluate the anticoagulant activity of extracts of sixteen species of Indian marine green algae, including the species of *B. plumosa*, which cold and hot water extracts were prepared, rich at sulphated polysaccharides, their chemical constituent's sulphate, sugar, protein and uronic acids. The extracts of *B. plumosa* exhibited higher activity with values of 88.9 and 55.9 IU/mg.[96]

### Antileishmanial activity

Cruz *et al*. showed that the Kahalalide F depsipeptide founded in *E. rufescenes* and algae of the genus *Bryopsis* spp., show activity against promastigotes of *L. donovani* and *L. pifanoi* with $LC_{50}$ values of 6.13 ± 0.16 and 8.31 ± 0.40 μM respectively, also tests were performed against amastigotes of *L. pifanoi* with $LC_{50}$ values of 29.53 ± 1.07 μM.[93,97,98]

## CONCLUSION

This present review offers basic studies on current knowledge for further studies of *Bryopsis* sp. The studies have provided a simple biological and scientific information for some ethno-pharmacological uses. Due, some of the studies offers partial and low dates related with activities reports of type of green algae. Which is of great interest in the field of phytochemical analysis due that constructed research methodology most solids. Therefore, the increase in research favors the condensation of the importance of the metabolites and compounds related to each of the pharmacological activities and as precursors for the isolation of future molecules in the development of new therapies for the future.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## ABBREVIATIONS

**Akt:** Protein kinase B; **BAEC:** bovine aortic endothelial cells; **BPL:** *Bryopsis plumosa* lectin; **BHT:** Butylated hydroxytoluene; **DNA:** Deoxyribonucleic acid; **DPPH:** 2,2-diphenyl-1-picrylhydrazyl; **DW:** Dry weight; **IC:** Inhibitory concentration; **isoKF:** Isokahalalide F; **KF:** Kahalalide F; **LC:** Lethal concentration; **NAD(P):** Nicotinamide adenine dinucleotide phosphate; **PI3K:** Phosphatidylinositol 3-kinase; **PUFA:** Polyunsaturated fatty scids; **spp:** Species; **UV:** Ultraviolet.

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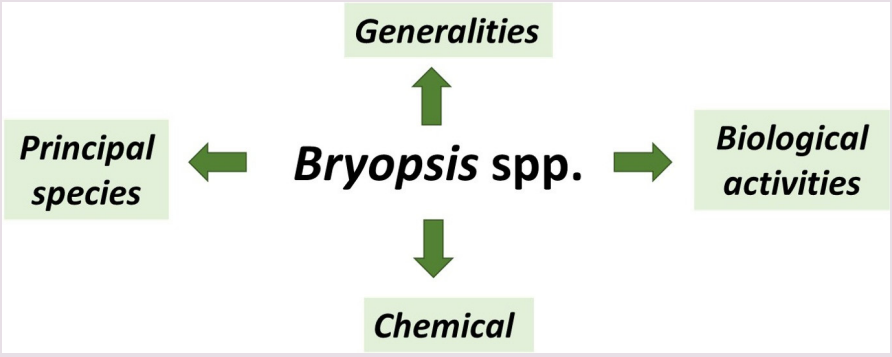
**GRAPHICAL ABSTRACT**



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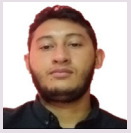

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