Review Article

A Review on the Historical Development of Phytoplankton in the Philippines and their Biological Importance throughout the Years

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ABSTRACT

Microalgae or commonly known as phytoplankton are the earliest and oldest forms of life on this living planet and considered as tiniest plant in the archipelago. These organisms display different colorations in water such as green, blue-green and brown. At present, phytoplankton are gaining much attention for feed, food and other important products in various fields and industries yet they are thought of as the most poorly studied group of aquatic organisms. Noteworthy, some of the microalgae which exist already in the commercial market are Spirulina, Chlorella, Haematococcus and Chaetoceros. Because of this, industrial microalga is a field that needs to be exploited primarily to produce promising high-valued chemicals for nutraceuticals, functional food and living feed and other feed additives. Additionally, these creatures were visualized as the "food for the future" because of the many applications that it possess. Historically, the first microalgae to be commercialized for food industry was the Nostoc species over many decades and consumed in China, Taiwan, Japan and other Southeast Asian Nations. Briefly, Nostoc species is a blue-green alga and sometimes called freshwater grapes which are in a jelly-like ball surrounded by thick mucilage. Thus, this review article aims to present the background antecedents of how phytoplankton discovered and existed in the Philippines for many decades and to discuss various phytoplankton with their biological components necessary for agriculture, fisheries, industrial, pharmaceutical, medical and other fields of endeavor.
Key words: Biological, Chemical, Constituents, History, Minute.

INTRODUCTION

Algae are polyphyletic assemblage of organisms that are diversely found in nature which can be in the form of one-celled, multi-celled, filamentous, made up of simple reproductive structures and can live in harsh, extreme conditions. These species are divided into either macro or micro algae with microalgae or commonly known as seaweeds which can grow up to 50 meters long and above (e.g. Genus *Macrocystis*). Microalgae or phytoplankton are tiny, floating and self-feeder organisms which are found and evenly distributed in various bodies of water in which the species can synthesize their own food. Most of the species are unicellular but some are colonial which are usually structured uniformly. Microalgae are segregated into hierarchical position and eventually identified by certain cell characteristics such as to their cell shape, cell size, cell wall flexibility, presence of chloroplasts and definite pigments and the number of the flagella.[1]

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BODY

Historical antecedents

The 1853 to 1862 algal collections by Bailey and Harvey isolated the first Philippine Diatom. Likewise, the work of O'Meara in 1872 isolated the Genus *Navicula* from the Sulu Archipelago.[2,3] In the 1900's, Mann in 1925 published a book on marine diatoms of the Philippines and this was followed by several studies on both marine and freshwater diatoms.[2] Also, the diversity of phytoplankton at Lake Bato in Camarines sur contained 61 genera was studied.[4] Moreover, the abundance of phytoplankton in Manila Bay,[5] subsequently the presence of microalgae in the ponds and pools in Manila and its vicinity[6] and later the diversity of phytoplankton in Laguna de Bay[7] were surveyed and conducted. Diatoms and dinoflagellates in Northwestern Luzon[8] and Northwestern Iloilo[9] were also examined and identified. Recently, microalgae distributed in the seven (7) lakes of San Pablo City and the Crocodile Lake in Los Baños were isolated and cataloged.[10] In addition, four (4) phyla of microalgae was also noted and studied in Lake Paoay and Lake Mohicap,[11,12] and.[13] More recent, microalgae including cyanobacteria found on the walls of the various buildings of the University of the Philippines, Los Baños, Laguna were isolated and identified. The morphological and cytological structures of the Chlorophycea and Bacillarophycea micro algal species were documented.[14] Likewise, micro algal species were evaluated at the Fish Cage Belt at the Magat Reservoir, Philippines. Phytoplanktons such as *Scenedesmus spp. Nitzschia spp.* and *Closterium spp.* dominated the area. Also, water quality assessment such as the temperature, pH and dissolved oxygen was gathered on the said reservoir.[15]

The following morphological features and taxonomic identification are according to the studies conducted on the diversity of various ecosystems and places in the Philippines. Chlorophytes or commonly known as the green algae are typically unicellular but some are multicellular or even colonial in nature. They are typically found in freshwater, but some species are seen in the sea. These microalgae are composed of membrane-bound chloroplasts, nuclei and flagella bearing 2-4 cells. They are green in color due to the presence of chlorophyll *a* and *b* embedded in the chloroplast. Many species can duplicate asexually by fission and sexually by iso- or anigamous. These species can invade various aquatic ecosystems such as freshwater, marine habitats and terrestrial areas. Freshwater green algae includes charophytes; marine microalgae includes chlorophytes and terrestrial species are mostly trebouxiophytes. Cyanophytes or the blue-green algae are well-known for its affinity to bacteria and typical called the blue-green algae. The species are prokaryotic and their sizes ranged from 0.2-2 um. The cells do not have nuclei and lack double membranes as well as chromosomes, but capable of duplication. However, the cell walls are double-membrane bounded organelles making them rigid. Their bodies are made up of large vacuole for buoyancy control. Just like any other microalgae, the various species can also be colonial and filamentous in habit. They were identified as components of the Pico plankton particularly in the temperate areas like the country. Finally, the Bacillariophytes or the diatoms which are ubiquitous, autotrophic, unicellular, filamentous or colonial and free swimming organisms. They are mostly colorless, but photosynthetic in nature. Scientists observed that this phylum is also facultative heterotrophic. Most of the species have a unique characteristic which is the presence of siliceous skeleton or frustule. The siliceous box of these organisms are composed of cytoplasm, nucleus and vacuole. Moreover, the body itself is also made up of chloroplasts which are yellow brown in color because of the xanthophyll such as fucoxanthin pigment dominating over that of the chlorophyll *a* and *c*. Species of this phylum are important in lakes because they are source of food for the zooplankton.

Biological components

Phytoplankton have an amazing number of biological compounds necessary for industrial and biotechnological purposes. The following are some of the discovered and reported compounds excreted by the algal flora. Micro algal species are made up of various Essential Fatty Acids (EFA) or EFA for a healthy diet in order to grow, develop and meet the dietary requirements.[16] These compounds are the structural and physiological components of lot of lipids and different phytoplankton have varied EFA components depending on the biological functioning of the species.[17] Phytoplankton have also Sterols which are one of the vital constituents of these organisms and tagged as the blueprint of organic matter in the aquatic habitat.[18] Depending on the functionality of the micro algal species, it varies in terms of sterol metabolic component as well as biological pattern. Cholesterol is the most abundant sterol having variety of sources and functions.[19] Generally, carotenoids have become prominent value added-product from algae particularly in the US with a market value of 1.2 billion and gaining more because of its health benefits circulating in the world[20] such as for food supplements, vitamin increments and feed additives for both poultry and aquaculture.[21] This pigment has 600 various types derived from 40 carbon chain. The most active type is the B-carotene which acts as pro-vitamin A, additive in multivitamin supplements and promote an antioxidant capacity. *Dunaliella* spp. and *Spirulina* spp. contain this compound making them ideal as food supplements and feed nutritive value.[22] Astaxanthin is a carotenoid with a red-colored pigment and considered to be the super vitamin E because of its antioxidant capacity[23-25] and has a defense mechanism to certain organisms.[26] It is also the pigment used to protect organisms from strong ultra-violet rays and DNA alterations in skin fibroblast.[27] This pigment has been examined in some aquatic organisms including microalgae such as *Dunaliella salina* and *Spirulina maxima* and found in crustaceans such as shrimps and fishes like salmon and trout. It is costly in salmon farming containing 15% of the total production[28] hence, the most important carotenoid in salmons and in trout.[29] Another carotenoid pigment is Lutein which is known to delay the occurrence of cataract, decreasing the vision particularly the age-related diseases and prevent from blindness by making the eyes healthy and free from any danger. This pigment is also responsible in the natural coloration of foods and cosmetics.[30-32] The market value of this pigment is also increasing just like the other carotenoids from 139 million dollar to 233 million dollar. *Chlorella* sp., *Muriellopsis* sp. and *Scenedesmus* sp. are the first microalgae to be discovered with lutein.[21,32] Beta-Carotene is considered as one of the most significant type of carotenoids, this pigment has the same activity with the Vitamin A or retinol for human body.[33] This is also used as coloring agent and in pharmaceutical and cosmetic industry.[17,20] This compound has proven to be a strong antioxidant which scavenge free radicals and fight cancers and other diseases.[33] The market value of this pigment increased from 261 million dollar as of 2010 to 334 million dollar by 2018. *Dunaliella* strains are the largest group of microalgae to produce large quantities of beta-carotene.[20] Phycobiliproteins are water-soluble compounds and light capturing proteins excreted by many micro algal species.[34] The metabolite is in 3 forms according to ultraviolet absorption such as phycocyanin, phycoerythrin and allophycocyanin. It is a component of the natural dyes made by pharmaceutical and cosmetic industries, used as fluorescent tags and immunological diagnostics agents. The compound was first observed in the cyanobacteria *Spirulina* sp.[20] Recently, it was observed in 2 other cyanobacteria namely *Oscillatoria* sp. and *Scytonema* sp.[35] It has a market value of 5-10 million and above.[36] Another is the Polyunsaturated fatty acids or PUFAs which are polymeric and have several types namely docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), arachidonic acid (AA) and gamma linolenic acid (GHA). These are also nutritional and functional foods or ingredients in the animal diet including fishes. It has a market value in the US of about 7.2 billion dollar in 2011 and reached 13 billion dollar in 2017.[20] The sources of these fatty acids are from fishes but poorly act as additives having huge stability extracted from algal oils depending on physical parameters such as changing culture conditions like temperature, light intensity and concentration of nitrogen.[37-39] Various marine and freshwater marine algae are made up of the different PUFAs. Also, these compounds are incorporated in infant and full term food formulas for healthier growth, develop the infant brain and to fight disease causing microorganisms.[40,41] In addition, Beta- Glucan are also compound which are known traditionally as Zymosan in Norway in the 1940's but finally named beta glucan in Italy in the 1960's because it was found in the baker's yeast particularly in its cell wall.[42] This pigment is important in human health as well as in fish's lifestyle for bacterial attack and infection.[43] *Chlorella* spp. are the major sources of this metabolic compound.[44] Finally, Mycosporine-like amino acids or MAA's which are compounds that are prominently synthesized by marine and some freshwater microalgae. However, the most primitive maker and producers of these secondary metabolites are cyanobacteria.[45] The unique characteristic of these compounds includes high ultraviolet absorption.[46]

Phytoplankton species have been out in the commercial market for several years. A number of them have been very successful in invading the regional, national and international markets. Four (4) phytoplankton are highlighted and their importance as natural food, supplement and pharmaceutical products were discussed. *Spirulina* spp. or *Arthrospira* exist as free-floating filaments with cylindrical multicellular trichomes, can tolerate high pH and can thrive in alkaline hot lakes.[47,48] It can be found in freshwater and seawater habitats both in tropical and temperate regions and can live either in alkaline and salty waters.[49-51] It is excellent in protein for its nutritive value[39,52,53] with an amino acid component of 62-68% more than enough compared to the components of beef, rich in vitamins A and B, contains beta carotene ten times than carrots, made up of essential fatty acids and linoleic acid, as well as linolenic acid, eicosapentaenoic acid, docosahexaenoic acid and arachidonic acid and a polysaccharide named Immulina where it improves the immune system of animals.[54-56] This cyanobacterium is one of the most useful species for commercialization for healthy food, animal supplement and nutritional products with health benefits.[57-59] It is also the first micro algal species that dominated the commercial industry for many years after the establishment of *Nostoc* sp. as the first commercialized microalgae in Asia with many therapeutic and toxicological studies that have been conducted and reported.[17] It was emphasized as food for tilapia;[60] rockfish[61] along with other microalgae species namely *Chlorella* spp., *Isochrysis* spp., *Scenedesmus* spp., *Pavlova* spp., *Dunaliella* spp. *Chaetoceros* spp. and *Tetraselmis* spp.[62] Consequently, *Spirulina platensis* together with *Oscillatoria* sp. and *Nostoc muscorum* with concentrations ranging from 82-100%[63] as well as *Dunaliella* sp., *Tetraselmis* sp. and *Chlorella* sp. in their acetone extract[64] were evaluated and proved to be effective for their antifungal activities. These are due to the presence of long chain of fatty acids such as palmitoleic, oleic, linoleic and linolenic acid as an attribution of their antifungal activities[65,66] In addition, *Spirulina platensis* along with *Anabaena oryzae, Nostoc muscorum* and *Phormedium fragile* as well as the Genus *Oscillatoria* sp. were also proven to kill nematodes hence, acted as nematicidal agent.[67] Correspondingly, Genus *Spirulina* is used as a feeding supplement and functional food to intestinal flora like *Lactobacillus* and *Bifidus*.[68] In humans, consuming the *Spirulina* products lowered the cholesterol level of the human serum.[69] As to the impairment of the bone marrow, the metabolites phycocyanin stimulate hematopoiesis, thus, regulating hormones needed to rehabilitate the damage. *Spirulina* also treats hypocholesterolemia, hyperlipidaemia and Artherosclerosis.[70] The effectivity of this micro algal in food and feed industry is because of the incorporation of the whole biomass of the algae providing green colorant thus, escalating the nutritional values.[71] Another is *Chlorella* spp. which are unicellular or colonial microscopic organisms containing the two (2) chlorophylls *a* and *b*. These organisms contain 45% of protein, 20% of lipid, 20% of carbohydrates and other vitamins and minerals,[48,72] They are easy to cultivate because it requires simple conditions such as the presence of water, carbon dioxide, light and some minerals only.[73] The largest producer of *Chlorella* worldwide is the Taiwan Chlorella Manufacturing and Co. found in Taipei, Taiwan. The company generate approximately 400 tons of dried micro algal biomass per year.[74,75] It is also known and prominent in ASEAN countries and to the United States with a total sale of 38 billion dollars and above annually.[76] It was first cultivated in 1910 for aquaculture industry as animal feed in Berlin, Germany.[77] Most of the commercialized *Chlorella* is in the form of capsule and caplets.[17] In Japan, the *Chlorella ellipsoidea* is commercialized and used as a dietary aid for powdered green tea, soup, noodles, rolls, cookies and ice cream.[75] Likewise, it is also sold in the market of Japan as colorant with a name "Lina-blue".[78] This genus is also a component of the healthy diet of humans and other forms of animals. The species is also used for medication such as treating anemia, gastric orders, constipation, wounds and hypertension. In addition, this algal species proved to escalate the concentration of hemoglobin, lower down sugar levels and an agent for hepatoprotective activity. This species was found to have the metabolite glucan which serve as a free radical scavenger reducing the blood lipids and increase the energy and wealth of most leprosy patients.[74,75,79] In specific, the species *Chlorella zofingiensis* produced also the metabolite astaxanthin under conditions of limited nitrogen and no presence of light for pharmaceutical purposes.[80] This species also excrete other metabolites useful for beauty and personal skin products to promote glowing and natural beauty.[81] *C. pyrenoidosa* and *C. vulgaris* are also made up of amino acids such as glycine and proline which are rich in biological fragments.[82] In addition, *Chlorella vulgaris*.[83,84] *Dunaliella* sp., *Synechocystis* sp. and *Tetraselmis* sp.[85,86] together with other micro algal species namely *Nostoc muscorum, N. humifusum, Anabaena flos aquae, A. oryzae, Spirulina platensis, Phormedium fragile, Wollea saccata* and an unknown species of the Genus *Oscillatoria* were identified with strong antioxidant activity in their aqueous forms. The study was done through the DPPH assay and species have percentage of antioxidative capacity of 30.1%-72.4% with compounds such as phenols, terpenoids, alkaloids; phycobiliprotein pigments and flavonoids which are effective as antioxidant and tumoristatic activity.[87] In other study, *Chlorella vulgaris* together with *Dictyochloropsis splendida* and *Scenedesmus obliquus* were also examined for their antioxidant capacity yielding high presence of carotenoids and phenols[88,89] and together with *Nannochloropsis oculata* and *Tetraselmis tetrathele* were also investigated to have an inhibitory activity against lipid peroxidation to linoleic acid so having an antioxidant activity.[90] Meanwhile, *Scenedesmus* spp. are green algae can tolerate various physiological conditions such as temperature from 15 to 40°C; optimal temperature of 30°C[91] and pH of neutral or 7.[92] For this, *Scenedesmus* is conceived to be viable as source of biological applications.[93] This is also due to the huge amount of nutritional components such as protein, lipids, carbohydrates and other trace elements.[94] Likewise, it is ideal as food constituents and animal feed and additives.[95] These organisms are identified as nutritional food source commonly added in desserts, fruit pudding and soup but the commercialization is still limited.[75] Although in few studies, the extracts of this species together with *Chlorella sp.* are used for human consumption[96] in which this species generally produced polysaccharides that act as oxidative agent[97] and extracellular enzymes or exoenzymes to degrade environmental pollutants.[98] In specific, *Scenedesmus costatum* have proven to excrete a long chain of fatty acids causing the species an antibacterial agent against aquatic bacteria along with diatom, *Thalassiosira rotula* and *S. costatum* which are composed of antibacterial compound oxylipins[17] and *Chaetoceros muelleri* and *Dunaliella salina*[99] and *Chlorella spp.* have antibacterial activities with isolated mixtures of fatty acids and chlorellin inhibiting both gram positive and gram negative microorganisms particularly bacteria.[100-102] Similarly, this microalgae can also treat and manage wastewater, hence, it has a dual role such as treatment of wastewater and producer of biomass.[103,104] Finally, *Dunaliella* spp. are eukaryotic photosynthetic organisms which are made up of two or more flagella for locomotion.[105] It is capable of tolerating high demand of salt concentrations in a given habitat. Thus, halotolerant microalgae which naturally occurs in salted lakes contains up to 10% of beta carotene under stressful conditions such as low nutrient and salt.[106] *Dunaliella* spp. can be found in various habitats in oceans, seas, salt lagoon and salt marshes. These algae are mainly the source of carotene or carotenoids in the commercial market. In specific, *Dunalliela salina* has an estimated market size of 10-100 tonnes per year and has a market prize of 750 per kg. The main producers are Australia, Israel, USA, China.[107] This is cultivated in large scale by the open pond system and protected by the carotenoid pigment against high level of climatic conditions.[108] This algal species is ideal for biofuel production due to its intracellular lipid content of 67% of the total dry weight.[109] It is also used in molecular farming or commonly known as biopharming where it expressed the hepatitis B surface antigene gene that makes the vaccine and antibody production more uncostly.[110,111]

CONCLUSION

Therefore, these phytoplankton are diversified in terms of characteristics, components and utilization. There are still a lot to discover on these minute, little organisms with vast array of biological importance. Moreover, utilization of the phytoplankton itself and their components are unexplored and dearth of micro algal studies which are deemed necessary to boost and hone this another small but gigantic era of biological field of study. Furthermore, discovery of experts on this endeavor is vital to boom this phytoplankton research and development.

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CONFLICT OF INTEREST

The authors declare no Conflict of interest.

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