Nanoparticles green synthesis macroalgae-based and its application and distribution in Indonesia – An overview

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Abstract. Nanoparticles have received much recent attention in areas such as chemistry, physics, materials science, life sciences and engineering. Many physical and chemical methods have disadvantages such as high costs, the use of chemicals that are harmful to the environment and health. The green nanoparticle synthesis approach, using plant extracts as a capping agent of nanoparticles, is the right solution to produce nanoparticles that are effective and environmentally friendly. Micro and macroalgae in the use of nanoparticle synthesis are increasingly being developed. However, the use of Sargassum in chemical applications has not been fully explained, and there are still some drawbacks that must be overcome. Sargassum spp. biomass has been recognized as a natural, renewable, and cost-effective material to become a capping agent for nanoparticles. This review is a summary highlighting the potential of metal-Sargassum composite-based materials as an alternative to biological protective activities, such as antibacterial. Synthesis and characterization of materials, key factors influencing material performance, and distribution of Sargassum in Indonesia are considered by the Government of Indonesia and investors in seeing opportunities to use Sargassum as an advanced material.

Keywords: characterization; green synthesis; Indonesia; nanoparticle; Sargassum sp.

1. Introduction
Nanoparticles receive a big research concern in areas such as chemistry, physics, materials science, life sciences and engineering. The high interest in nanoparticles is due to the unique optical, magnetic, electronic and catalytic properties with distinctive features on the size and shape of the nanoparticles [1, 2]. Many physical and chemical methods have disadvantages such as high costs, the use of chemicals that are harmful to the environment and cannot be applied in medicine because there are toxic capping agents [3]. These factors contribute to the investigation of new methods and materials for the production of nanoparticles based on the principles of ‘Green Chemistry.’ The emphasis in this approach is on the synthesis and application of nanoparticles for maximum social benefits, with minimal impact on ecosystems. Because both the synthesis and application of nanoparticles are important, many researchers from academia and industry focus on biological systems such as plants, marine algae, fungi and bacteria for the production of nanoparticles [4, 6]. Among the various biosynthetic approaches, the advantage of using plant extract are sustainable, safe handling, a board process of viability metabolite. The bioactive
compound that responsible for the synthesis of nanoparticles are terpenoids, flavones, ketones, aldehydes amides, etc.

The oceans are a rich source of many kinds of natural products. Seaweed is a plant that is often used by researchers and entrepreneurs as an added value material, one of which is nanoparticles. This is because the abundance of seaweed is very abundant, but it is still not widely used. Types of seaweed that can be used for the synthesis of nanoparticles that can be used as antibacterial, anticancer and mosquito-larvicidal properties are Galaxaura elongata [7], Sargassum ilicifolium [8], Sargassum muticum [9], Sargassum glaucescens [10], Sargassum polycystum [11], Turbinaria ornata [12], Enteromorpha compressa [13] and Cystoseira baccata [14]. Sargassum macroalgae have become the object of considerable research, especially in the synthesis of nanoparticles. This is because sargassum macroalgae have bioactive compounds such as proteins, lipids, carbohydrates, carotenoids, vitamins and many other secondary metabolites with various biological activities. Various biological properties of sargassum have been reported, which include antibacterial, anti-diabetic, antioxidant, and anti-inflammatory properties [6,15]. However, the use of sargassum in the industry in Indonesia has not been widely developed. This study is expected to be used as a reference for the Government of Indonesia and investors in looking at the prospects for sargassum, especially as a cheap and environmentally friendly raw material for nanoparticles.

In this study, it will explain the development of research and use of nanotechnology throughout the country to the development of the nanomaterial user industry in Indonesia. In addition, the nanoparticle synthesis method using sargassum and its application was also studied. The decomposition of the synthesis method aims to inform the most effective, easy, fast, and inexpensive process for the manufacture of nanoparticles. This study aims to provide an overview to the government and businessmen regarding the potential of sargassum macroalgae as an economical marine biota because many sectors can use these nanoparticles to provide added value to products because of the characteristics and wide distribution of sargassum in nature.

2. Abundance of Sargassum in Indonesia

Abundance is the number of individuals who occupy a certain area or the number of individuals per unit area or per unit volume [16]. Abundance can also be interpreted as a simple measurement of the number of species present in a community or trophic level [17]. The factor that can affect the population of algae abundance in marine waters is a hard and sturdy substrate that serves as a place to attach. This seaweed plant can only live in waters that get enough light. Clear waters, seaweed can grow and develop to a depth of 20-30 meters. The nutrients needed by seaweed can be obtained directly from suspended nutrients in seawater [18]—for example, the abundance of Sargassum sp. The Barracuda Beach area is very good and quite dense. This is because the condition of Barracuda Beach is very open and gets enough sunlight for the growth of Sargassum sp.

The area of coral waters in Indonesia is approximately 6800 km² [19]. These waters are a seaweed growing area. Seaweed producing areas include coastal waters that have reef flats, such as the Riau Islands, Bangka-Belitung, Seribu, Karimunjawa, the Sunda Strait, the southern coast of Java, Bali, West Nusa Tenggara, East Nusa Tenggara, islands in Sulawesi and Maluku [20]. Alginate-producing seaweed from the Sargassum clan is mostly found in the Sunda Strait, which is around the area around the reaches of 500 to 900 g/m² and the number of species obtained is seven species.

The types of macroalgae that are often found on Dofamuel Island are the types of the Phaeophyta division (6 species). This is because the types of phaeophyta divisions have good tolerance to waves found in tidal areas. Types of macroalgae that are generally resistant to waves will grow well, for example, macroalgae from the Phaeophyta Division (Sargassum, Turbinaria, Padina). Sargassum is a macroalgal that is able to form a unique environment by associating with other marine organisms so that it can defend itself and survive in marine waters.

The results of a local production survey of local residents show that in Kambuno Island, South Sulawesi, the density of natural Eucheuma biomass reaches 7 tonnes/km². In the Mentawai Islands, West Sumatra Gracilaria 31.4 tonnes/km². In the Sunda Strait, Sargassum reaches 5-10 tons/km². The south
coast of Java Island Gelidium 2-5 quintals/km² and Sargassum 5-15 tonnes/km². Production in the Riau Islands in 1979 was 251.4 tons from a coastal area of 84 ha. The islands in South Sulawesi in 1979 reached 142 tons and Maluku in 1979 as many as 4,301 tons [21].

The southern coast of Java Island is one of the seaweed habitats with a stable substrate condition. Seaweed from the family Gelidium, Gellidiella, Gracilaria and Sargassum can be found in the Pameungpeuk-Gurat, Binuangeun, Cilurah-Pandeglang and Krakal-Wonosari areas [22]. In Bali, Lombok, Moyo, Sumbawa, Kupang, East Kalimantan, Baran Lombo, Baran Ca in South and Southeast Sulawesi, Kwandang, North Sulawesi, Tagulandang, Ruang, Pasige and Sangir-Talaud are dominated by seaweed from the clans Halimeda, Padina, Sargassum, Gracilaria, Bornethella and Acanthophora [23]. In addition, Ambon, Seram, Kai, Gorong, Tanimbar and Maisel are dominated by the clans Caulerpa, Codium, Ulva, Dictyota, Padina, Sargassum, Amphiroa, Gracilaria, Halimenia, Hypnea, and Acanthophora [24]. Table 1 shows the density of sargassum in Indonesian waters.

Table 1. Density of Sargassum in several locations in Indonesian waters [25].

| Location                      | Harvest (g/m²) | Presence (%) | Density (g/m²) | Distribution of reef flats (m²) |
|-------------------------------|----------------|--------------|----------------|--------------------------------|
| Pulau Kambuno, Sulawesi selatan | 33             | 50           | 17             | 150                            |
| Siburu                        | 5              | 3            | 1              | 100                            |
| Marak                         | 5              | 3            | 1              | 100                            |
| Pisang                        | 50             | 13           | 7              | 100                            |

From table 1, it can be concluded that the sargassum harvest in Indonesia is 10,950 g. If it is assumed that the need for sargassum in synthesizing 1000 ml of nanoparticles is 10g, then Indonesia can produce around 1095 L of metal nanoparticles or the equivalent of US $ 7,697,490. This indicates that the prospect of sargassum as a nanoparticle is very good and can increase the economy of both the country and investors.

3. Nanotechnology developments in the world and Indonesia

Research and application in the scope of nanotechnology have developed rapidly in the last decade [26]. The latest technology has penetrated various sectors of life, such as textiles, food, cosmetics, health, food packaging, and various other consumer products. According to Hoerudin and Irawan [27] the rapid development of nanotechnology is a challenge and an opportunity for a country to play a role in the world market or it will only become a market destination. The final result of research in the field of nanomaterials is to change the technology from micrometer-scale materials to nanometer-scale materials-based technology. This is based on the belief that nanometer-sized materials have physical and chemical properties superior to bulk materials. These properties can be changed by controlling the size of the material, adjusting the chemical composition, surface modification, and controlling the interactions between particles. Nanotechnology has a wide application area and impact ranging from the fields of advanced materials, transportation, space, medicine, cosmetics, electronics, agriculture and food processing, environment, IT, to energy.

Leitch et al. [28] point to increasing interest in the nanotechnology industry in 'nano-1-dimensional' configurations such as layers and coatings and an increase in manufacturing process patents. Coating and coating products are in great demand by industry because they cover the primary needs of humans and industries, thereby increasing the economy of the nanotechnology industry. Layer and coating products are applied as laminates, such as packaging materials to corrosion inhibitors. These products are very important because these products will be consumed continuously. In addition, products for specific therapeutics are the most rapidly developing nanotechnology from 2007-2011. This specific therapeutic product includes various types of drugs and antiseptics, one of which is drug delivery and antibacterial. The main objective in designing drug delivery systems with nanoparticles is to control the particle size, surface properties and release of the active compound in order to obtain the particular pharmacological action of the drug at the dosage regimen.
The latest data released by the Nanotechnology Products Database shows that in July 2020 the number of nanoproducts marketed in the world market reached 8874 products, produced by 2454 companies from 62 countries [29]. The largest number of nanotechnology products produced by companies in the United States, far exceeding nanotechnology products produced by other countries. In 2020, Indonesia already had 14 industries that produce nanotechnology products. Nanoparticles that have been used for commercial products in Indonesia are silica oxide, aluminum oxide, titanium aluminum nitride, silver. Some of the products that have used nanotechnology are supplements (diabetes, cholesterol-lowering, osteoporosis, stomach, antioxidants), textiles (antibacterial, anti-odor, allergy), cosmetics (nutrition, moisturizer, lightening, skin nourishing, antioxidants), agriculture (fertilizers, durable water storage), surface (oxidation protection, heat resistance), house cleaning (antibacterial), petroleum (lubricant additive, injection well, corrosion-resistant), automotive (UV stability, anti-pollution, hydrophobic, waterproof, oil-resistant). This is also consistent with the nanotechnology roadmap in Indonesia designed by the Ministry of Industry 2010-2025. Industry in Indonesia has applied nanotechnology in the ceramics, textiles, food, automotive, and polymer sectors.

The focus of 3rd phase of the road map planned by the Ministry of Industry is energy storage and converters. This research has long been developed in various countries. One of the applications of nanoparticle technology is the manufacture of carbon in the nanometer size or so-called carbon nanoparticles (CNPs). CNPs are widely used as supercapacitors [30], high-performance electrode materials in batteries, and good photoluminescent materials [31]. CNPs are not only used as energy storage but also as antibacterial [32]. CNPs can be obtained from several bottom up techniques, namely pyrolysis [33-36], microwave plasma by increasing chemical vapor deposition [37, 38], liquid salt electrolysis [39], particle graphitization to obtain polymerization microemulsion [28, 40], laser vaporization of carbon pellets [41], and treatment in supercritical water [31, 42].

It has been mentioned that one of the resources that can be used as a storage area for energy is carbon. One of the sources of carbon that is quite a lot is marine organisms, such as macroalgae. This needs to be further developed regarding the potential of macroalgae as a carbon source for energy storage.

4. Phytochemical analysis of sargassum
The secondary metabolite of seaweed extracts such as flavonoids, phenols, citric acid, ascorbic acid, polyphenolic, terpenes, alkaloids and reductase can act as reducing agents [43]. The bioactive compound in the seaweed extracts was shown in table 2.

Methanol extract is more efficient than aqueous extract due to methanol extract contained a lot of secondary metabolites have 12 different species of Sargassum extract had high antibacterial activity against human pathogenic bacteria [44]. Similarly, Methanol extract of Sargassum plagiophyllum is active to inhibit Gram-positive bacteria [45], while acetone extract of Sargassum tenerrimum showed high activity against all tested strains. The interesting information is a green synthesis of silver nanoparticles by exploiting seaweed has immense antibacterial than other extracts. The study showed that seaweeds containing phytochemicals could be better opted for nanoparticle synthesis.

The result of the recent study showed that the extract of S. wightii, S. tenerrimum, S. angustifolium, which contained several phenolic compounds, could exhibit a greater antioxidant activity. In addition phenolics are strong antibacterial compounds and antibacterial properties of several plants are related to their phenolic contents. Table 1 shows S. wightii and S. tenerrimum have phenolic content and ability as antibacterial. Tropical conditions affect phytochemical constituents of the plants especially phenolic content, particularly in marine organisms. Targete et al. [49] suggested that there was a significant difference in phenolics of algae related to the climate conditions.
Table 2. Phytochemical analysis of *sargassum* sp.

|                          | *Sargassum wightii* (Tamil Nadu) [6] | *Sargassum wightii* (Bengal) [46] | *Sargassum tenerrimum* [47] | *S. angustifolium* [48] |
|--------------------------|-------------------------------------|-----------------------------------|-----------------------------|-------------------------|
| flavonoids               | +                                   | +                                 | +                           | +                       |
| saponins                 | -                                   | -                                 | +                           | +                       |
| tannins                  | -                                   | +                                 | +                           | +                       |
| alkaloids                | +                                   | +                                 | +                           | +                       |
| phenolics                | +                                   | NA                                | +                           | NA                      |
| steroids                 | +                                   | +                                 | NA                          | NA                      |
| amino acid               | NA                                  | -                                 | +                           | NA                      |
| carbohydrate             | NA                                  | +                                 | +                           | NA                      |
| sterols                  | NA                                  | NA                                | +                           | +                       |
| protein                  | NA                                  | -                                 | +                           | NA                      |

[+] present, [-] absent, [NA] None.

5. *Sargassum*-metal nanoparticle

5.1. *Synthesis and Characterization*

Brown algal contained high polysaccharides and hydroxyl groups. The results of Mata *et al.* [50] confirmed there is the participation of hydroxyl groups during biosynthesis of AuNPs using *Fucus vesiculosus*. Fucoxanthins, which are carotenoids that rich in hydroxyl groups and are algal pigments, can also contribute with respect to gold reduction as these have good reducing properties [51]. Fucoidans refer to a type of polysaccharide that contains considerable percentages of L-fucose and sulfate ester groups [52]. Control of the size and structure of the resultant nanoparticles could be related to the interactions between bio-compounds such as polysaccharides, proteins, polyphenols and phenolic compounds and metal atoms. Table 3 shows the characterization of metal nanoparticles with various sargassum that have different bioactive compounds.

Table 3 shows that, in general, the plasmon peak shifts toward higher wavelengths (redshift) from 408 to 436 nm for AgNP, meaning an increase of the particle size [60]. At a higher concentration, the AgNPs begin to aggregate and form into large particles [60]. Besides, the observed increase in the plasmon absorbance with rising alga concentration indicates a greater amount of Ag+ reduction. With increasing volumes of extract, the intensity of the SPR band increased; with further higher volumes of extract, the particles were not stable. According to the literature, an excess of reducing agents may result in instantaneous particle precipitation [61]. The uncoated particles undergo uncontrolled growth and aggregation phases.

It was also observed that the production of nanosize silver particles starts almost immediately on the addition of the reducing agent and continues throughout the investigated period, as indicated by the emergence and the progressive increase in the intensity of the well-defined plasmon band. The increase in absorbance is observed when the rate of silver nanoparticle formation has increased and more particles are formed during the same time. In this review, various types of sargassum are used to synthesize AgNP, which varies considerably according to the method used. If the synthesis used a high-temperature heating method, the reaction time required is very fast. If the synthesis is heated to a lower temperature (45 °C), the time needed is about 1-4 hours [62]. However, for the synthesis process that uses room temperature and does not carry out the stirring process, it takes a longer time (24 hours) [63]. With the increase of temperature, the reduction occurred very fast and the intensity of the SPR band also increased. In this review, the nanoparticle synthesis process is carried out using the inverse synthesis method, where the process of mixing metal salts with sargassum extract is carried out directly.
Table 3. Synthesis and characterization of nanoparticles with various Sargassum.

| Sargassum        | Location                  | Pretreatent | Powdered                          | Aquous extract | Synthesis of NP                                                                 | Characterization of NP                      | References |
|------------------|---------------------------|-------------|-----------------------------------|----------------|--------------------------------------------------------------------------------|---------------------------------------------|------------|
| Sargassum wightii| -                         | - Washed    | - Dried at room temperature for 10 days - Blending | - 20 g seaweed with 100 ml water - Temp 60 °C for 20 min | - 50 ml of 1 mM AgNO₃ was treated with 5 ml Extract of sargassum - Incubate 28 °C for 24 h | Crystallite size: 17 nm Size: 5-22 nm Shape: spherical SPR: 439 nm | [53]       |
| Sargassum wightii Mandapam | - Washed    | - Dried at room temperature for 3 weeks - Blending | - 10 g seaweed with 100 ml water - Temp 60 °C for 30 min - Lyophilized | - 88 ml of 1 mM AgNO₃ was treated with 12 ml Extract of sargassum - Incubate for 24 h | Size: 18.45-41.59 nm Shape: spherical SPR: 420 nm (Abs: 10) | [6]        |
| Sargassum tenerrimum Mandapam, Tamilnadu | - Washed    | - Dried at room temperature for 15 days - Grinding | - 200 mg seaweed with 100 ml water - Temp 60 °C for 20 min | - 95 ml of 1M AgNO₃ was treated with 5 ml Extract of sargassum - Mix 90 °C for 20 min | Size: 20 nm Shape: spherical SPR: 420 nm (Abs: 2.4) | [47]       |
| Sargassum cireneum Vagator and Dona Paula | - Dried in incubator for 2 days at 37 °C | - 25 g seaweed with 200 ml water - boiled for 30 min | | - 45 ml of 1 mM AgNO₃ was treated with 5 ml Extract of sargassum | Size: 45-76 nm SPR: 408 nm | [54]       |
| Sargassum dentifolium Hurghada | - Washed    | - Air dried - Grinding | - 1 g seaweed with 100ml water - Temp 100 °C - Filter | - 50 ml of 1M AgNO₃ was treated with 50 ml Extract of sargassum - Stirred for 4 h at 45 °C | Size: 113-155 nm SPR: 420 nm (AgNP) Shape: roughly spherical | [55]       |
Table 3. Synthesis and characterization of nanoparticles with various Sargassum (continued).

| Sargassum     | Location          | Pretreatent Powdered                                  | Aqueous extract                         | Synthesis of NP                                                                 | Characterization of NP | References |
|---------------|-------------------|------------------------------------------------------|-----------------------------------------|---------------------------------------------------------------------------------|------------------------|------------|
| *Sargassum myriocystum* | Mandapam, Tamilnadu | - Washed under sunlight  
- Chopped to smaller size  
- Grinded to pasta | - 15 g seaweed with 150 ml water  
- boiled 60 °C for 20 min  
- Filter  
- Stored 4 °C | - 900 ml of 1 mM AgNO₃ was treated with 100 ml Extract of sargassum  
- Incubated for 24 h under dark condition | Size: 30-150 nm  
SPR : 420 nm (AgNP)  
Shape: spherical | [56] |
| *Sargassum glaucescens* |  | - 10ml extract seaweed with 50 ml water  
- stirring | -20 ml of 5 mM HAuCl₄ was treated with 60 ml Extract of sargassum  
- mingled for 4 h at room temp under dark condition  
- Centrifuge for 20 min  
- parched overnight at 30 °C with vacuum | Size: 2-5.3 nm  
SPR : 538 nm  
Shape: spherical | [11] |
| *Sargassum muticum* | Persian Gulf | - 1 g seaweed with 100 ml water  
- Heated 100 °C | - 50 ml of 0.1 mM HAuCl₄ was reacted with 50 ml aquous Extract of sargassum  
- Stirring at 45 °C for 1 h | Size: 4.3-6.6 nm  
SPR : 550 nm  
Shape: spherical | [57] |
| *Sargassum muticum* | Persian Gulf | - 1g seaweed with 100 ml water  
- Heated 100 °C | - 50ml of 1mM HAuCl₄ was reacted with 50 ml aqueous Extract of sargassum  
- Stirring at 45 °C for 1 h | Size: 4.3-6.6 nm  
SPR : 520 nm  
Shape: spherical | [58] |
| *Sargassum myriocystum* | Mandapam, Tamilnadu | - Washed  
- Dried  
- Powdered  
- Store 4 °C | - 1g seaweed with 20 ml water  
- boiled for 5 min  
- filtered and centrifuge | - 45 ml of 1mM HAuCl₄ was reacted with 5 ml aqueous Extract of sargassum  
- Stir it up at room temperature | Size: 4.3-6.6 nm  
SPR : 547 nm  
Shape: spherical | [59] |
### Table 4. Development of nanoparticle studies using sargassum macroalgae.

| Macroalgae       | Metal | Method                                                                 | Characterization of NP                                                                 | Application                                                                 | References |
|------------------|-------|------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------|------------|
| *Sargassum sp*   | ZnO   | Material: Zinc nitrate, Extract of sargassum, Method: Calcination      | Size: increase (607-649 nm) with increase volume ratio (5-20% v/v)                    | NA                                                                        | [64]       |
|                  |       |                                                                        | Shape: hexagonal                                                                       |                                                                            |            |
|                  |       |                                                                        | Crystallite size: decrease (31.4 to 14.7 nm) with increase temp of calcination 400-600 °C |                                                                            |            |
|                  |       |                                                                        | Shape: Spherical                                                                       |                                                                            |            |
| *Sargassum wightii* | ZnO  | Material: Zinc nitrate, Method: extraction of sargassum using ethanol | Size: 20-62 nm                                                                         | Reduce the fitness and reproduction of the malaria vector Anopheles stephensi | [65]       |
|                  |       |                                                                        | Shape: spherical                                                                       | and cotton bollworm Helicoverpa armigera                                    |            |
|                  |       |                                                                        | Geometry: FCC                                                                          |                                                                            |            |
|                  |       |                                                                        | SPR: 378 nm                                                                            |                                                                            |            |
| *Sargassum muticum* | ZnO | Material: Zinc acetate, Method: inverse synthesis. Alga (powder) was mixed with water distillation and heated at 100 °C | Size: 30-57 nm                                                                         | Cancer supplement                                                           | [66]       |
|                  |       |                                                                        | Shape: hexagonal                                                                       |                                                                            |            |
|                  |       |                                                                        | SPR: 334 nm                                                                            |                                                                            |            |
| *Sargassum cinereum* | Ag  | AgNO3 was treated with extract of sargassum and stirred for 3 h         | Size: 45-76 nm                                                                         | Antibacterial                                                              | [54]       |
|                  |       |                                                                        | SPR: 408 nm                                                                            |                                                                            |            |
| *Sargassum tenerrimum* | Ag | Material: silver nitrate, Preparation: Extract was prepared by heating at 60 °C for 20 min | Size: 20 nm                                                                            | Antibacterial                                                              | [47]       |
|                  |       |                                                                        | Shape: spherical                                                                       |                                                                            |            |
|                  |       |                                                                        | SPR: 420 nm                                                                            |                                                                            |            |
| *Sargassum dentifolium* | Ag | Material: silver nitrate, Preparation: heated at 100 °C               | Size: 113-155 nm                                                                        | Biomedicine                                                                | [55]       |
|                  |       |                                                                        | Shape: spherical                                                                       |                                                                            |            |
|                  |       |                                                                        | SPR: 295 nm and 420 nm                                                                 |                                                                            |            |
| *Sargassum myriocystum* | Ag | Material: silver nitrate, Method: incubation for 24 h under dark condition | Size: 20 ± 2.2 nm                                                                       | Biological and enviromental application                                    | [56]       |
|                  |       |                                                                        | Shape: hexagonal                                                                       |                                                                            |            |
|                  |       |                                                                        | SPR: 420 nm                                                                            |                                                                            |            |
| *Sargassum wightii* | Ag  | Material: silver nitrate, Alga (powder) was diluted to mili Q and heated at 60 °C for 20 min | Crystallite size: 17 nm                                                                | Antibacerial                                                               | [53]       |
|                  |       |                                                                        | Size: 5-22 nm                                                                            |                                                                            |            |
|                  |       |                                                                        | Shape: spherical                                                                       |                                                                            |            |
|                  |       |                                                                        | SPR: 439 nm                                                                            |                                                                            |            |
| Macroalgae            | Metal | Method                                                                 | Characterization of NP                                                                 | Application                                                      | References |
|-----------------------|-------|------------------------------------------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------|------------|
| *Sargassum polycystum* | Ag    | Material: silver nitrate, Optimum reaction temp: 60 °C                 | Size: 20-88 nm, Geometry: FCC, SPR: 418 nm                                              | Anti larvicide                                                   | [67]       |
| *Sargassum muticum*   | Ag    | Material: silver nitrate, Alga diluted to bidistillation water, heated and decanted | Shape: spherical, Geometry: FCC, Size: 43-79 nm, SPR: 438 nm                          | Vector control of mosquito (Aedes aegypti, Anopheles stephensi, and Culex quinquefasciatus) | [68]       |
| *Sargassum wightii*   | Ag    | Material: silver nitrate, Powder alga diluted to water at 60 °C and lyophilized | Size: 18.45-41.59 nm, Shape: spherical, SPR: 420 nm                                   | Enzyme inhibitor, Antibacterial, Antioxidant                      | [6]        |
| *Sargassum tenerrimum*| Au    | Material: AuCl4                                                        | Size: 5-57 nm                                                                         | Catalyst for reduction of nitro aromatic compound                | [69]       |
| *Sargassum Polycystum*| Au    | Material: HAUCl4, Powder alga diluted to water and heated for 15 min    | Size: 30-60 nm, Shape: spherical, SPR: 532 nm, Crystallite size: 15 nm, Geometry: FCC | Bacteria killer                                                  | [70]       |
| *Sargassum wightii*   | ZrO2  | ZrO(NO3)2·xH2O and extract of algae were mixed, fumaced at 400 °C      | Crystallite size: 4.8 nm, Shape: spherical, Size: 5 mm, SPR: 277 nm                   | Antibacterial                                                   | [71]       |
| *Sargassum* Ni-Fe    |       | Material: NiCl2, FeCl3, Method: add sargassum to Ni-Fe solution, calcination N2 and carbonation at 800 °C | Size: 8.1-10.2 nm                                                                   | Cracking catalyst                                               | [72]       |
Table 5. Comparative study of the antibacterial activity.

| Bacteria         | Concentration       | AgNO$_3$ | Extract | AgNP | References |
|------------------|---------------------|----------|---------|------|------------|
| S. wightii       | 0 µl                | 0        | 1       | 3    | N/A        |
| S. ternerrium    | 8 µl                | 9.5      | 10      | 8    | 9.5        |
| S. wightii       | Extract             | 1        | 0       | 1.5  | 0.5        |
| S. ternerrium    | Extract             | 1        | 0       | 1.5  | 0.5        |
| S. wightii       | 5 µl                | 5        | 5       | 7    | N/A        |
| S. ternerrium    | 5 µl                | 5        | 5       | 7    | N/A        |
| S. wightii       | 1 mM (30µl)         | 1        | 0       | 0.5  | 0.5        |
| S. ternerrium    | 1 mM (30µl)         | 1        | 0       | 0.5  | 0.5        |
| S. wightii       | 20 nm               | 17       | 18      | 16   | 17         |
| S. ternerrium    | 20 nm               | 17       | 18      | 16   | 17         |
| S. wightii       | 100 mic             | N/A      | N/A     | N/A  | N/A        |
| S. ternerrium    | 100 mic             | N/A      | N/A     | N/A  | N/A        |
| S. wightii       | 18.45-41.59 nm      | N/A      | N/A     | N/A  | 15         |
| S. ternerrium    | 18.45-41.59 nm      | N/A      | N/A     | N/A  | 15         |
| S. wightii       | 0.1 mM              | 0        | 0       | 0    | N/A        |
| S. ternerrium    | 0.1 mM              | 0        | 0       | 0    | N/A        |
| S. wightii       | 5 µl                | N/A      | N/A     | 17   | 11         |
| S. ternerrium    | 5 µl                | N/A      | N/A     | 17   | 11         |
| S. wightii       | 30-150 nm           | 15       | 7       | 15   | 11         |
| S. ternerrium    | 30-150 nm           | 15       | 7       | 15   | 11         |

References:
- [53] (1 µM, 30 µl)
- [47] (10 µM, 30 µl)
- [6] (100 µM, 30 µl)
- [54] (1 mM, 30 µl)
- [56] (100 µM, 30 µl)

Bacteria – 1. P. aeruginosa; 2. V. cholerae; 3. K. pneumoniae; 4. S. aureus; 5. E. coli; 6. S. typhi; 7. B. subtilis; 8. S. flexneri.
5.2. Utilization of metal nanoparticle-sargassum

The earlier studies reported that the seaweeds, Sargassum ilicifolium [8], Sargassum muticum [9], Sargassum glaucescens [10], Sargassum polycystum [11] are excellent source for the synthesis of nanoparticles that show the potential of antibacterial, anticancer and mosquito-larvicidal property. Development of nanoparticle studies using sargassum macroalgae served on (table 4).

Based on table 4, the relationship between the characteristics of the synthesized nanoparticles and the type of sargassum on their antibacterial ability. Silver compounds are toxic to microorganisms with strong antibacterial effects, including multi-drug resistant bacteria [73]. Similarly, electrostatic interaction between positively charged nanoparticles and the negatively charged bacterial membrane induces cell permeability resulting in cell death [74].

5.3. Comparative study of the antibacterial activity

Antibacterial activity is the most important characteristic of medical textiles to provide adequate protection against microorganisms, biological fluids, and aerosols, as well as disease transmission. Smaller AgNPs having the large surface area available for interaction would give more antibacterial effect than the larger AgNPs. It is also possible that AgNPs not only interact with the surface of the membrane but can also penetrate inside the bacteria [75]. The reduced size of silver nanoparticles with the 20–80 nm size ranges can instantly interact with the bacterial cell wall and release silver ions which could penetrate into the bacterial cell and attach to the thiol groups of proteins and they prevent the DNA replication, resulting in bacterial inactivation [76]. Roberts et al. [77] revealed that there was some variation in most of the physico-chemical properties of the biochar between species collected from different locations. Sargassum from different locations had very different yields (49 and 62%) and S content (0.9 and 2.8%) (table 5).

6. Conclusion

Sargassum can be utilized as a reducing and capping agent for metal nanoparticles. The reagent ratio, synthesis temperature, reactant concentration and make it possible to obtain outstanding results on qualitative parameters such as mean particle size. Sargassum can be used as a biomedicine application, such as antibacteria. Sargassum has the potential to be an advanced material that can increase the economy of both country and investors.

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