Microplastic stress induce bioresource production and response in microalgae: a concise review

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ABSTRACT
There are many literatures on the importance of bioresources from microalgae, but this review shows how microalgae are able to respond to the stress induced by microplastics (MP) and how the process leads to the production of bioresources. The study of these bioresources is significant because they are harnessed by man as energy and pharmaceutical tools. The extent of MP in the aquatic environment, microalgae stress induced by MP, the response of microalgae to stress induced by MP and bioresource production in microalgae due to stress induced by MP are described. The study shows that the presence of MP in the environment can induce nutrients and environmental stress, which enhances lipid accumulation and the production of other useful biotechnology resources. The study also shows that microalgae tend to produce resources that can respond to the stress induced by MP, which leads to a high removal efficiency of MP in aquatic ecosystems. The study also shows that the production of bioresources in the form of antioxidants, which are either enzymatic or non-enzymatic antioxidants, is the basic reason why microalgae are able to remove MP. A number of studies have shown the effect of MP on microalgae, while others have shown the efficiency of microalgae in the removal of MP from aquatic systems. But scanty literature exists showing how MP induces stress on microalgae. More studies are needed to show the mechanism and the concentration of bioresources produced by microalgae under the stress of MP.

1. Introduction
The poor method of plastic management in developing countries such as Nigeria is worrisome due to the risk associated with these pollutants on the proper functioning of the aquatic ecosystem [1]. Several studies have been documented on the effects and management of larger plastics, but scanty literature exists on the fate, effects and management of MP, which is a product of larger plastics [2]. MP are types of emerging contaminants that are worrisome due to the effect they exert on aquatic flora and fauna [3,4]. MP are pollutants that are less than 5 mm in length [5,6]. They are the bye-products of cosmetics, pharmaceuticals, clothing, and industrial processes [7,8]. These pollutants persist in the aquatic environment, leading to bioaccumulation across the trophic level [9]. MP are substances whose environmental and health effects have yet to be determined due to a lack of knowledge about the interactions and toxicological effects of the contaminants [10]. The types of MP include antibiotics, surfactants, pesticides, pharmaceuticals, personal care products, effluents and nanomaterial [11]. The limited information on the environmental fate of MP is responsible for the lack of management technology and the inability of regulatory agencies to develop proper regulation [12].

Microalgae are microscopic, unicellular plant-like organisms that range in size from a few to a hundred micrometres [13]. They are referred to as the most important tool in the aquatic ecosystem because they are the primary producers in the aquatic ecosystem [14]. Microalgae can form biofilms with MP, leading to the formation of extracellular polymeric substances (EPS) [15,16]. This is detrimental to the balance of the aquatic ecosystem due to the dependence of aquatic fauna on microalgae [17]. MP has been shown to cause blockage of the digestive tract, alteration of feeding habits, disruption of feeding urge, growth retardation, and reproduction inefficiency in aquatic fauna [18,19].

Microalgae are able to prevent the negative effect of MP on aquatic organisms by responding to any effect [20]. The response tends to counteract the effect of MP on the microalgae, thereby preventing the accumulation of MP on the surface of microalgae and associated substrate [21]. This response also led to the production of bioresources that are harnessed by...
man as energy and pharmaceutical bioresources [22]. There are many literatures on the importance of bioresources from microalgae, but this review is the first to show how microalgae are able to respond to the stress induced by MP and how the process leads to the production of bioresources.

2. Extent of MP pollutants in aquatic environment

The increasing generation of plastic waste is due to the increase in the production of plastic and the manufacturing of plastic related materials. 23, reported that about 275 million metric tons of plastic was produced in 2010 by coastal countries. 24, reported the production of about 6300 million metric tons of plastic worldwide [24]. A small proportion of the plastic produced is recycled while a larger proportion is released into landfills and aquatic bodies [23]. An MP is produced when plastic material breaks down into pieces ranging from 5 millimetres to 100 nanometres [25]. MP can also originate from other sources, including paint, domestic, sewage and other wastewaters [26]. The two sources of MP are primary and secondary sources of MP. Primary MP are MP that are produce from product such as personal care products, hand cleaners facial cleaner and tooth paste [27]. This is because majority of these compounds contain PP (polypropylene), PE (polyethylene) and PS (polystyrene) [28]. Secondary MP is MP resulting from the breakage of larger plastic pollutants [29]. These pollutants are originated from land-based sources, which result from plastic littering and improper management of landfill sites [30]. 31, reported that the larger amount of MP in the aquatic environment is as a result of secondary sources [31]. This study stressed that the majority of MP in the aquatic environment is due to the breakdown of polymers such as LDPE (low density polyethylene), HDPE (high-density polyethylene), PP and nylon. This breakage is due to photo-oxidation assisted degradation caused by UV radiation and microorganism assisted oxidation [32]. Weathering and mechanical forces including wave action and abrasion with sand also play a significant role in the breakage of plastic into MP [33]. MP is heterogeneous pollutants due to their difference in size, shape, density and chemical composition because they are product of different plastic substance [34]. Studies have shown that MP tends to accumulate in aquatic biota and substrate, leading to unbalance in the aquatic environment because of poor knowledge of the extent of MP in the aquatic ecosystem [26]. The route of entry of MP into the aquatic environment is as a result of the discharge of domestic and industrial wastewater [35,36]. MP in leachates can also enter the aquatic environment from landfill as a result of runoff into the nearby aquatic environment [37]. Recent studies by 38, on the distribution of MP in freshwater show variation in the concentration of MP among different freshwater sources, including stormwater, wetland, lake, river, estuarine, stream, glacier, and snow after analysis of 109 studies. The study reported a higher concentration of MP in the glacier and snow with a n value equal to 878. The high concentration of MP in glaciers and snow over the rest of the freshwater source is due to the net accumulation of MP during snow deposition due to the narrow chance of being washed off. Whereas, MP in the other sources of freshwater can be easily washed off by runoff even after accumulation [38].

MP is persistence in the water column and sediment of the aquatic environment, as reported by 39. The persistence nature of MP is the reason why Ellen MacArthur Foundation predicted that the amount of MP will exceed the total number of fish in the aquatic environment [6]. The aquatic sediment is referred to as the long-time sink for MP due to the deposition and accumulation of MP in sediments [39]. A recent study by 40, demonstrated that the deposition and accumulation of MP in aquatic sediment tends to vary with depth, with sediment in the upper layer having more MP than sediment in the deeper layer. This study shows that recent sediment has higher MP than older sediment [40]. A critical review by 41, gives details on the methods and concentration of MP detected by various researchers in different water sources [41]. MP is toxic to aquatic organism and also acts as a substrate for the aggregation of toxic pollutants [42]. This toxicity is as a result of the ingestion of MP which bioaccumulate and biomagnify across the food chain and food web. The bioaccumulation and biomagnification across the trophic level is due to the variation of MP in shape and density. This diversification of MP is the reason why organisms at every stage of the trophic level tend to ingest and accumulate MP [43].

3. Microalgae stress induced by MP

MP tends to accumulate in aquatic biota due to its slow degradation rate [44]. The accumulation of MP is detrimental to microalgae and makes microalgae the sole responsibility of MP flow across the trophic level [45,46]. MP also tends to negatively affect microalgae, leading to oxidative stress. The stress induced by MP to microalgae includes nutrient induced stress, environmental induced stress and oxidative induced stress [47]. MP exposure to microalgae and its effects based on many effect criteria has been well summarized by 48.

MP induces nutrient stress on microalgae due to its ability to accumulate and magnify in the aquatic ecosystem. The accumulated MP stimulates the formation of biofilm, with the MP serving as the substrate [49]. This biofilm increases the use of nutrients present in the aquatic ecosystem, leading to nutrient starvation
The state of nutrient starvation is referred to as nutrient stress because the process leads to the production of a high amount of reactive oxygen species (ROS) [50,51]. The advantage of nutrient stress is that the microalgae accumulate more lipid and also produce more bioresources in order to counteract the effect of ROS [52]. MP is able to accumulate and transport harmful pollutants in the aquatic environment [9]. This phenomenon hinders the penetration of sunlight, causes oxygen depletion and changes in the temperature of the water [53]. This environmental factor alteration leads to stress on the microalgae, increased lipid accumulation, and an increase in bioresource production [54]. The high production of bioresources is intended to cancel out any effect of ROS caused by oxidative stress caused by changes in environmental factors (Figure 1) [55]. MP accumulation also alters the salinity and pH of the aquatic environment. The ability of microalgae to withstand the stress induced by salinity varies from species to species because the stress tends to interfere with the process of photosynthesis [56]. The optimal pH for the growth of microalgae ranges from 8.2–8.7 and is also dependent on the species involved [57].

4. Response of microalgae to stress induce by MP

Microalgae are the most important component of the aquatic environment due to their role as producers in the food chain and food web [58]. The increased level of MP in the aquatic ecosystem is alarming because of its negative impact on microalgae which induce stress [59]. This stress leads to the alteration of the morphology and physiology of the microalgae [60]. In order to counteract the effect induced by MP, microalgae develop various response mechanisms which lead to the development of useful bioresources [22]. Microalgae are able to respond to the stress induced by MP pollutants via morphological changes [61]. Microalgae forms biofilm with MP and other toxic pollutants acting as a substrate, this biofilm tend to limit the amount of sunlight that penetrates into the aquatic ecosystem and also increases the utilization of nutrients present in the system [62,63]. The limiting of sunlight penetration leads to oxidative stress, while the increased utilization of nutrients leads to nutrient starvation in the system [64]. Microalgae are able to counteract any effect that may result from stress caused by the limitation in sunlight penetration by increasing the amount of cellular chlorophyll production [65]. Although, the limitation of sunlight leads to a reduction in microalgae growth and volume, the higher cellular chlorophyll produced by the microalgae annuls any effect caused by the stress by the utilization of the available sunlight energy present in the system [66]. Nutrient starvation also causes stress in the microalgae, which affects biomass production, but microalgae are able to counteract the effect by the production and accumulation of more lipids in the microalgae cell [67]. The aggregation of toxic pollutants by MP also increases the pH and salinity of the water, thereby contributing to the environmental stress induced on the microalgae [68]. Both the environmental and nutrient stress induced by MP on microalgae lead to oxidative stress which involves increases in the amount of ROS produced by the microalgae [69]. The increase in ROS produced by the microalgae is the reason why the growth and biomass production of the microalgae is retarded [70,71]. This effect is due to the ability of ROS

![Figure 1. Stress induce on microalgae by MP.](image-url)
to damage the deoxyribonucleic acid (DNA) of the nucleus, chloroplast and mitochondria [72]. The damage to these organelles, which are the vital parts of the microalgae, causes mutation and genetic instability [73]. Microalgae are able to annul any effects associated with over production of ROS by an antioxidant and non-antioxidant response mechanism (Figure 2) [74,75]. A detailed review on how microalgae are able to respond to over production of ROS can be found in the study of 21.

5. Mp induce bioresources production in microalgae

A number of studies have shown the strategies that can be used to enhance the production of bioresources by microalgae [77]. The available studies have placed emphasis on the manipulation of conditions to cause nutrient and environmental stress [78,79]. The current study shows that the presence of MP in the environment can also induce nutrients and environmental stress which enhances lipid accumulation and production of other useful biotechnology resources [80]. MP can either cause a negative effect on the microalgae biomass concentration or have no inhibitory effect on the morphology of microalgae [81]. The production of bioresources in the form of antioxidants, which are either enzymatic or non-enzymatic antioxidants is the basic reason why microalgae are able to remove MP from water, Although there is scanty literature showing bioresources production by microalgae under MP stress as presented in Table 1 [82]. The ability of microalgae to degrade MP is dependent on the production of a high amount of ROS, which stimulates the release of an enzyme that is meant to scavenge the excess ROS produced [83,84]. The enzymatic and non-enzymatic antioxidants that are produced in high amounts to counteract the effects induced by MP include polyphenol, carotenoid, proline, ascorbic acid, tocopherol, superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and glutathione reductase (GR) [85]. This antioxidants are produced by microalgae in response to the stress induced by MP [86]. These antioxidants are biological compounds that help the microalgae under the stress of ROS overproduction by quenching ROS and inhibiting lipid peroxidation [87,88]. This is why microalgae lipid accumulation increases under environmental and nutrient stress induced by MP [89].

Polyphenols are referred to as chemical compounds that contain hydroxylated aromatic rings [90]. They are classified based on the number of units representing phenol in the compound [91]. They are the most abundant and secondary metabolites derived from microalgae due to their strong antioxidant properties [92]. They are the most important biotechnological tools that are useful in medicine as anticarcinogenic, antimutagenic, and anti-inflammatory compounds [93]. These

![Figure 2](image_url). Response mechanisms of microalgae to stress induce by MP (a) MP stress induce (b) Enzymatic antioxidant response mechanism c non-enzymatic antioxidant mechanism (d) mechanism of radical scavenging by ascorbic acid [76,109].
Table 1. Microplastics induce bioresources production in microalgae.

| SN | Microalgae               | Type of Microplastics | Bioresources Produce | Bioresources Function                  | Application of Bioresources                                                                 | Reference                  |
|----|--------------------------|-----------------------|----------------------|----------------------------------------|---------------------------------------------------------------------------------------------|----------------------------|
| 1  | *Chlamydomonas reinhardtii* | PS                    | SOD, CAT and POD    | Antioxidant protection                 | Due to its tendency to minimize free radical damage to the skin, SOD is employed as an anti-aging ingredient and antioxidant in cosmetics and personal care products. CAT is a useful tool in the food industry for the removal of hydrogen peroxide from milk prior to cheese production. It’s also useful in the wrapping of food to prevent oxidation. It is useful in the removal of hydrogen peroxide from fabrics in the textile industry. POD is used as biosensors in analytical systems for the determination of hydrogen peroxide and organic hydroperoxides. They are also useful in the determination of choline, glutamate, alcohol, and glucose when co-immobilized with hydrogen peroxide. | [113,117,118]               |
| 2  | *Phaeodactylum tricornutum* | PP, PE, PET and PVC   | Chlorophyll and carotenoid | Indication of oxidative stress         | Chlorophyll contains vitamins, antioxidants, and therapeutic characteristics that improve human health. Carotenoid are transformed into vitamin A because they are beneficial antioxidants that can protect people from disease, improve immune system function and eye health |                          |
| 3  | *Scenedesmus obliquus*    | PS                    | GPx and GSH          | Oxidative stress biomarkers            | GPx and GSH are important tools in industry and medical biotechnology.                      | [119–121]                  |
| 4  | *Acutodesmus obliquus*    | PE, PP and PVC        | Lipid                | Oxidative stress biomarkers            | Biofuel Production                                                                         | [122]                      |
| 5  | *Chlorella pyrenoidosa*   | PS                    | malondialdehyde      | Oxidative stress biomarkers            | Oxidative stress biomarkers It is medically used as a biomarker to show oxidative stress in diseases like cancer, psychosis, chronic obstructive pulmonary disease, asthma, or cardiovascular illnesses. | [124,125]                  |
| 6  | *Spirulina sp*            | PP and PE             | Phycocyanin          | Oxidative stress biomarkers            | Phycocyanin is medically regarded as an ingredient for a potential cancer drug because it can enhance the regeneration of blood cells and improve the immunity of the body system by increasing the efficiency of the lymphocyte activity and lymphatic system, leading to the enhancement of disease resistance. | [126,127]                  |
compounds are produced by microalgae under stressful conditions to counteract the oxidative stress caused by nutrient and environmental factors [94]. This study predicted that prolonged exposure of microalgae to MP tends to increase the production of polyphenol compounds because, in the presence of MP, the production of ROS increases [95]. This prompts the need for the antioxidant system in order to annul any effects caused by the exposure [96]. Although there is scanty literature showing the effect of MP on microalgae polyphenol production, a study by 97, depicts the variation in phenolic compound production as a function of the species of microalgae grown in industrial wastewater [97]. This is an indication that the ability of microalgae to produce polyphenol compounds is dependent on the source of stress, the species of microalgae involved, and the extent of MP in the environment.

Another important non-enzymatic biomolecule produced by microalgae under the stress of MP is proline, tocopherol, and ascorbic acid, which are important biotechnological tools used in medicine [98,99]. Proline, for instance, is a vital biomolecule in the synthesis of protein due to its unique properties as a secondary amine [100]. Although proline is a type of non-essential amino acid due to the ability of the human body to produce it, proline has been linked to the ability to heal the skin of people who do not produce or store much proline. Deep study into the use of proline has linked L-proline to osmoprotection, making it a vital pharmaceutical and biotechnological tool [101,102]. The ability of microalgae to tolerate the stress induced by Mp is also due to the presence of proline [103,104]. This stress induced by MP causes the increased production of proline by microalgae in order for the microalgae to counteract the oxidative effect resulting from the higher level of ROS produced by the microalgae [105] (Figure 3). Proline is utilized as a supplement for growth medium, especially in tissue culture experiments, due to its ability to prevent plant stress and increase plant yield [106]. This shows that the production of proline by microalgae during stress induced by MP prevents oxidative stress on the growth and yield of microalgae biomass [107]. Tocopherol and ascorbic acid are the most important medical and pharmaceutical tools derived from microalgae under stressful conditions due to the presence of vitamins in both antioxidants [108]. Both antioxidants tend to deliver hydrogen ions in order to quench the activities of free radicals [109]. The ability of tocopherol and ascorbic acid to donate hydrogen atoms to ROS is due to the weak bond in the antioxidants, which is about 10% weaker than the bond of polyphenols (Figure 3) [110]. The ability of microalgae under stressful conditions to successfully annul the effect of ROS could also be linked to their ability to produce tocopherol and ascorbic acid [111].

Enzymatic antioxidants are another important biosource produced by microalgae under stressful conditions. These molecules are produced in response to stress induced by MP due to their ability to annul any effect of ROS produced by the microalgae [109]. Enzymatic antioxidants tend to transform ROS and its metabolic products into harmless compounds. They tend to prevent the peroxidation of microalgae lipids and maintain the structure and function of the

Figure 3. Microalgae increase in proline, ascorbic acid and tocopherol in response to stress induce by MP.
6. Conclusion

The current study shows that MP tends to induce nutrient and environmental stress on microalgae. This stress increases the rate of ROS production, leading to oxidative stress on the microalgae. Microalgae tend to respond to the stress induced by MP by accumulation of lipids and production of bioresources, which are important biotechnological and medical tools. These bioresources are produced by microalgae in order to counteract any effects resulting from the exposure of the microalgae to MP. A number of studies have shown the effect of MP on microalgae, but scanty literature exists showing how MP induces stress on microalgae. There is also scanty literature showing how the stress induced by MP causes the production of some bioresources such as tocopherol, polyphenols, proline, and ascorbic acid. More studies are needed to fill in this gap and also show how the concentration of these bioresources tends to vary under the stress of different MP.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability statements

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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