Review article

Large-scale Production and Application of Graphene Oxide Nanoparticles to Meet Agriculture Needs

R. Jino Affrald*

Faculty of Allied Health Sciences, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam-603103, Tamil Nadu, India

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Abstract

The success of the agricultural sector is crucial to the whole world's prosperity. Reducing hunger and poverty and enhancing food security and nutrition have all made great strides in recent decades. Improvements in resource efficiency and food safety brought about by productivity and technical gains have not been shared fairly. Fortunately, it is possible to reduce the adverse effects of the current global food production system on the environment and climate with the aid of technological advancements. Nanotechnology can be integrated into the agricultural sciences as "nano agriculture", to provide solutions that are more accurately boost production without negatively impacting the environment. Among a range of nanoparticles, graphene oxide (GO) has found diverse application in electronics, optics, medicine, and supercapacitors. Due to its adaptability, it is also crucial in many critical biological contexts. Graphene oxide has a range of potential uses in industries as diverse as agriculture, technology, and food production. Nanoencapsulation of nutrients, smart-release systems, novel packaging, smart water treatment systems for various kinds of microorganisms and pollutants, pesticide and insecticide detection and analysis, and other kinds of detection systems are all possible applications of this versatile material. It may also be a part of fertilizer or used as a plant growth stimulant. In the GO market, yield is a major concern. With so much focus on graphene, it is essential to produce GO nanoparticles in large quantities. A possible method for industrial-scale graphene manufacturing is the oxidative exfoliation of graphite. This review outlines few cost effective strategies to mass-produce GO for use in agriculture.

*Corresponding author: Tel.: (+91) 44 4741 1000
E-mail: jinoaffrald.ja@gmail.com

1. Introduction

Agriculture is one of the most critical industries to expand a country's economy. Agriculture in India accounts for more than 70% of all jobs, contributing to one-third of the country's gross domestic product. In the past, the nation's expansion was impeded by problems in the agriculture sector [1]. Graphene is quickly becoming a hot topic of discussion in various scientific fields, including chemistry, physics, and materials science. Graphene's extraordinary physical properties, such as its capacity to be chemically tweaked, have piqued the interest of a significant number of scientists [2]. There is still a considerable amount of work to be done before completely understanding the possible applications of graphene in technology. It should be no surprise that graphene in conductive substrates and high-current density conductors in broadcast electronics, liquid crystal display screens, and solar cells, are some of this material's most potentially fruitful applications [3]. Graphene has ushered in a new phase of "relativistic" condensed mathematics, one in which hitherto unthinkable quantum relativistic occurrences may now be duplicated and examined in a laboratory [4]. The future uses of graphene in biomedical applications such as drug delivery systems, biochemical sensors, antimicrobial materials, and biodegradable scaffolds for cell development have been the subject of a tremendous amount of research until this point [5]. Manufacturing graphene oxide on a massive scale has been the focus of some researchers.

In contrast, others worked to improve its structure and conducted additional research into the material's physical characteristics [6]. Graphene oxide (GO) is being utilized to develop cutting-edge technologies, including plant growth stimulators, nano fertilizers, nanoencapsulation, smart-release systems, antimicrobial agents, innovative packaging, water treatment, ultrafiltration, pollutant removal, pesticide, and insecticide analysis, detecting devices, and precision agriculture. Despite this, a few challenges must be conquered before the graphene-based nanoparticle can be used to its full potential [7].

2. Properties of GO Nanoparticles

There still exists a dearth of information regarding how other factors, such as the surface chemistry, size, and charge of graphene structures may influence the physiochemical and mechanical capabilities of the final materials [8]. Because carbon nanotubes and graphene have similar chemical compositions, the edges of graphene that have been exfoliated can have their properties dynamically adjusted to facilitate the dispersion of polymer nanocomposites. When it comes to technological advancements, extremely porous graphite flakes have always had the potential to be employed in various applications that require electrostatic insulation, high thermal conductivity, high energy absorption resistance, and high fracture toughness [9]. Because oxygen atoms are arbitrarily functionalized on the puckered graphene sheet, GO might not have much structural coherence. It is feasible to regulate the optical emission from GO by modulating the oxidation process. This is made possible due to the confinement effects formed when graphene sheet oxidation occurs. Graphene is a semiconducting material. However, GO has ferromagnetic properties. If the carboxylic groups in GO are removed, it should change from being a semi-metal to a semiconductor [10].

Electrophilic Fukui functions are used to pinpoint the areas of each structure responsible for chemical activity [11]. The presence of water-bound between the layers of GO results in the material having an extraordinarily high hygroscopicity. No matter which process is used to generate GO, it is never possible to completely get rid of the water that has been physically adsorbed. According to Boehm and his colleagues' findings [12], the inter-crystalline swelling property of graphite oxide causes the distance between the layers to change depending on the water vapor partial pressure present in the environment. Due to the magnetic separability of GO – iron oxide nanocomposites, it has been demonstrated that these catalysts are highly active and recyclable. Furthermore, these nanocomposites may be recovered and reused several times without significant activity loss [13]. Recent research on graphene's ferromagnetic properties suggests that carbon magnetism can be caused by various defects, half-hydrogenation corrugations, and topological structures [14].

3. Applications of GO Nanoparticles in Agriculture

Nanomaterials currently have a wide range of potential uses, including but not limited to the fields of electronics, healthcare, cosmetics, food processing, construction materials, and aerospace. These nanomaterials may be effective in helping to improve diagnostic, therapeutic, and prevention efforts [15]. There has been a significant amount of research published in the fields of natural and technical sciences on a wide variety of applications and facets of digitalization in agriculture, such as big data and wireless sensor networks, virtual worlds and robotic systems and sensors, 3D printers and systems engineering, cloud computing and intelligent systems, as well as digital twins and blockchains. This research has been conducted over the past several decades. On the other hand, the social sciences have produced an equivalent amount of literature on digitalization in the agricultural sector [16]. Graphene has been used profitably in various business sectors, including agriculture [7]. A number of the applications of GO nanoparticles are illustrated in Figure 1.

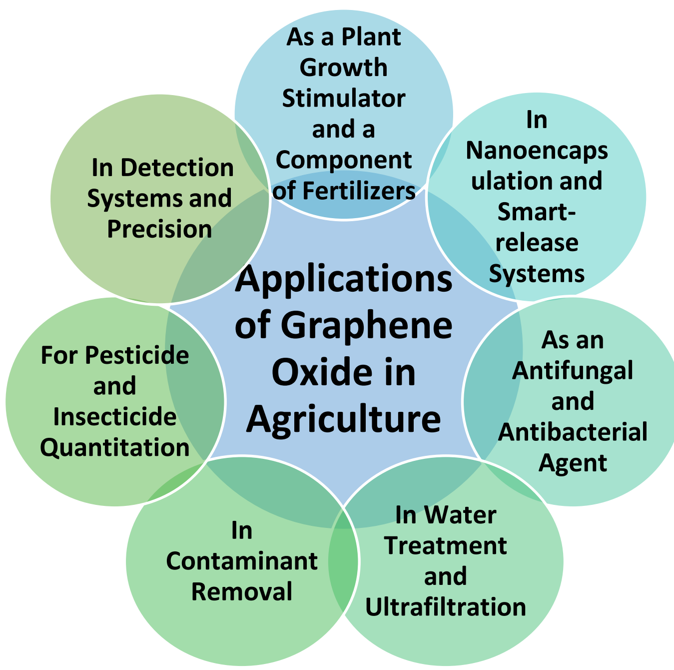

Figure 1. Applications of GO nanoparticles in agriculture

3.1 Seed germination

Based on current research, it has been found that Arabidopsis plants are capable of resisting the translocation of GO (graphene oxide) into their stems or leaves, despite GO being taken up by the plant through the root hairs. However, GO can be distributed in the cotyledon during the initial stages of plant growth [17]. The study's findings [18] showed that wheat cells treated with GO had elevated mitotic indices and abnormalities. Following treatment with GO, there was a reduction in the amount of chlorophyll. When the root cells of wheat seedlings were studied using transmission electron microscopy, no discernible morphological alterations were identified in the root cells [18]. The investigators [19] plucked three stems from watermelon seedlings and put them in identically sized styrofoam pots to research watermelon plants. The stems of these plants were scraped with tweezers to infuse them with 10,000 g/L of 10 L GO. In an experiment, *A. thaliana* plants were injected with GO solution once a week for a period of one month. The results showed that at the appropriate concentration, the growth and stability of the plants were significantly enhanced, as evidenced by increasing root length, leaf area, and number of leaves. The watermelons that had GO injected into them, on the other hand, had a larger circumference and a higher sugar content than watermelons that had not been treated [19]. In a separate study, the germination of seeds, the growth of seedlings, and the amount of cadmium ions absorbed by solution-cultured rice and maize were all investigated. According to the study's findings [20], the amount of solution-bound cadmium ions decreased in direct proportion to the amount of GO present in the sample. In response to higher amounts of GO and cadmium ions, rice seed germination, seminal root length, and blossom length were reduced [20]. In this study, the hydrophilic characteristics of GO were utilized to promote the germination and growth of plant seeds. It was discovered that adding even a trace amount of GO to soil significantly boosted the rate at which seeds of spinach and chives germinated. The tight interaction between GO and the soil grains caused GO to remain in the soil rather than escaping it as it would have otherwise. It is clear from all of these characteristics that GO has the potential to be a risk-free approach to improving plant production [21]. In recent studies, the impacts of GO on *Vicia faba* was analyzed, and the findings revealed both favorable and unfavorable outcomes. There was a correlation between GO (1600 > 200 > 100 mg GO) and decreased level of metabolic activity and an increased level of oxidative stress. The increased scavenging of hydrogen peroxide by GO led to an improvement in the health of *V. faba* [22]. At a concentration of 2000 g/mL, GO, on the other hand, increased both the root and stem lengths by 19.27% and 19.61%, respectively. There was no alteration in the structure of plant tissue, nor was there any accumulation of GO in the wheat root cells. With this information, it became possible to have a better understanding of the environmental safety of GO as well as the interactions between plant nanoparticles [23]. The effects of the GO on the germination of mung bean seeds were investigated. In these experimental conditions, the GO therapy produced a plant that was 25 cm longer than the control group's plant. However, the increased GO content did not impact the growth of the plant's mass, roots, or leaves [24].

3.2 Pesticide monitoring

Nanotechnology has the potential to be utilized in pest monitoring by developing high-performance nanomaterials. Recent years have seen a surge in interest in studying nano pesticides, nano fertilizers, and their potential use in many agricultural systems. When it comes to effective, broad-spectrum insect control, a wide variety of nano pesticides, such as silver and copper and nanoformulations, are superior to conventional pesticides [25]. The persistence and long-term stability of pesticide residue mean that its accumulation in the environment is becoming an increasingly serious threat to public health. The elimination of pesticides from the natural environment through the application of biological and chemical processes has recently rekindled the interest of scientists. The effectiveness of pesticide adsorption in aqueous solutions is significantly enhanced by GO, which has the potential to have beneficial effects on the environment as it can reduce pesticide residues in water purification processes [26]. The stereoselective removal of isomeric endrin and dieldrin pesticides from sample solution was demonstrated with the assistance of a nanocomposite consisting of GO and iron oxide magnetic nanoparticles. It was demonstrated that the endo-position of the oxygen in endrin, as opposed to the exo-position of the oxygen in dieldrin, is more favorable to the development of strong interactions between GO composites and biomolecules [27]. The GO embedded sandwich nanostructure has the potential to be utilized in the process of identifying molecules of dithiocarbamate while excluding other agricultural compounds from the investigation. According to the results of spiking experiments, the sandwich nanostructure can be recognized in both natural lake water and commercial grape juice without the need for any additional processing. Critical applications of GO include on-site monitoring and evaluation of pesticide residues in agricultural products and habitats [28]. Researchers have recently investigated various organophosphorus pesticides such as profenofos, phorate, isocarbophos, and omethoate using an aptamer sensor to understand their electrochemical properties. By utilizing an amide bond, the aptamer was then bonded to the GO/chitosan nanocomposite. Because of its high conductivity, monitoring the electrochemical response was not difficult. The electrochemical performance of the aptasensor was found to be superior, as was its capacity to bind and respond to profenofos, phorate, isocarbophos, and omethoate [29]. Hemin, a biomimetic sensor based on a P450 enzyme mimic, was used to study selectivity, while GO was used to analyze sensitivity. Both of these discoveries were made through the development of a biomimetic sensor. This sensor offered several benefits, including being simple to operate, having high sensitivity and selectivity, having a longer lifespan, and having the lowest possible price. An investigation into its selectivity was carried out so that it could be utilized in the collection of environmental samples. A piece of analytical equipment that was chemically pure, sensitive, and selective was obtained through the measurement of carbofuran utilizing the method that was proposed [30]. Quantum dots made of monodisperse boron nitride were created using GO as the substrate. The developed sensor possessed many impressive qualities, including high levels of stability, repeatability, and reproducibility. An electrochemical sensor was utilized to perform analyses on water and apple juice samples, and excellent sensitivity and selectivity were demonstrated in both cases [31]. Using a colorimetric technique that imitated the activity of horseradish peroxidase, it was possible to detect nanomolar levels of organophosphorus pesticides. This detection technique was developed in the 1990s. The LOD equivalent for the three pesticides, dimethoate, methyl paraoxon, and chlorpyrifos, was more than two times lower than the MRL in China's national food safety standard [32]. To put it another way, in contrast to commercial septa, the composite antenna generated an effective electrophysiological response, which indicated that it was capable of being assessed in the field. The increased potency of the pheromone used led to a rise in the number of insects that were successfully captured. Because of this method's long-term field efficacy and environmentally friendly nature, the amount of damage caused by insects was reduced to a satisfactory level [33]. The removal of organophosphorus pesticides was accomplished by using microextraction, with GO quantum dots serving as an innovative and efficient adsorbent. The dots were magnetically dispersed. When preparing a sample for analysis, many factors must be taken into consideration, including pH, the amount of donor phase present, the spinning rate, the harvesting length, and the adsorption conditions, which must include the type of solvent, the amount of solvent, and the disintegration time. Using this method, organophosphate pesticides were removed from water samples and fruit juice samples, and then they were able to be detected [34].

3.3 Soil microsensor

Monitoring the environment is an absolute must if one wants to see an increase in the production of crops with a higher yield. Farmers are starting to use sensors to supply data on their fields, which is a new method in the farming industry [35]. When making measurements in the field, a microsensor made of GO that is both affordable and incredibly sensitive and resilient is used. A humidity and soil moisture sensor based on GO and constructed with micro electro mechanical systems (MEMS) and with a diameter of 1500 m to 2400 m was developed by researchers. Even after approximately four months since the last adjustment of the sensor, there was no noticeable change in capacitance. Moreover, the adjustments made to the sensor did not significantly affect the temperature or soil conductivity, which refers to the concentration of salt in the soil. In the future, soil moisture may be analyzed at a variety of depths using the microsensor [36]. Electrochemical reactivity is required to form graphene quantum dots (GQDs) from GO. This procedure can be carried out at room temperature, and the size of the GQDs can also be altered. The features of a GQD microsensor for measuring soil moisture were investigated using two different soil samples. Comparison was made between GQDs sensors with and without passivation. The formation of H-bonds between GQDs and water molecules explains the sensing mechanism. The sensor resistance in red soil (silt loam) and black soil (clay) rises by 99 and 97%, respectively, when there is a 32% increase in the amount of water contained in the soil [37]. The GO-based array probe sensor has a reaction time of 140 s and a recovery time of 20 s for soil samples with a moisture content of 10%.

A method that was devised allowed the measuring of the moisture content of soil to a depth of 20 cm. The standard oven drying method and in-depth soil moisture profiling had a difference of 2.4%, which was the highest difference between the two [38]. In a separate line of research, fully printed microsensors were produced by combining laser micromachining processes with the same laser. This produced the best results. In a printed microsensor that consisted of five layers of GO film, both the capacitance sensitivity and the hysteresis were lower than 8% for humidity detection. When the relative humidity was lower than 84%, the response time was around 9 s, and the recovery time was approximately 5 s. This approach suggested an intriguing possibility for building high-performance, low-cost microsensors in the future [39]. As a direct consequence of this, a susceptible sensor based on graphene quantum dots was also developed. The technique was straightforward compared to other standard soil moisture sensors, and the utilization of GQDs ensured that the reduced sensing unit could be manufactured at a low cost. The sensor's sensitivity was increased when exposed to higher levels of moisture due to Grotthuss's chain reaction and ionic conductivity.

The micro-sensor, which had a response time of 2-3 min, was the fastest response time of any soil moisture sensor discovered to this day [40]. The first step was to use a lithographic approach to efficiently micro-pattern a solvothermal-assisted reduced GO known as "TRGO". The next step was to electroplate the surface of the micro-patterned TRGO with bismuth for the electrochemical detection of heavy metal ions. The designed micro-sensor had a detection limit of 0.4 g/L for lead ions and 1.0 g/L for cadmium ions. Both of these ions may be detected using the micro-sensor [41]. A sensor that can detect the presence of iron in water samples was developed as a direct result of the research from *Quercus ilex* fruits with a detection limit of 0.345 M iron ions via spectrophotometer and up to 7 ppm with naked eye [42].

3.4 Micronutrient delivery

It is feasible that slow-release fertilizers will be more successful than conventional sources of fertilizer while at the same time reducing the negative impact that excess nutrients have on the environment. Utilizing graphite rock, a natural resource that is both inexpensive and abundant, a functionalized GO was synthesized and tested as a novel phosphate ion carrier. This research aimed to improve the number of nutrients delivered to plants [43]. For graphene sheets to have any practical application, they first need to be functionalized and then spread out. Previously complex tasks like layer-by-layer building, spin coating, and filtering can now be accomplished with the assistance of solvent-assisted technologies. One example of this is using a solvent to functionalize graphene chemically. Because flake graphite must first undergo a chemical oxidation process before it can be functionalized, the surface area of functionalized graphene produced through covalent and non-covalent procedures is much less [44]. In order to highlight the benefits of GO carriers and their capacity to be utilized as a generic platform for the delivery of macro-and micronutrients, a comparison was made between the zinc levels in the soil left behind by GO-based fertilizers and those left behind by commercial soluble fertilizers [45]. An ever-increasing number of graphene researchers are utilizing radioisotope techniques to investigate the mineralization and release of GO. It was discovered that the conversion of GO to CO_2 was slowed down in soils that included vibrant microbial communities. The use of water to extract GO from the soil was unsuccessful. Because of its high biodegradability, homo/hetero-aggregation delivery may have restricted the amount of GO available, which may have led to a deficiency in mineralization and release [46]. At least one of the zinc-GO formulations has demonstrated that it has the potential to enhance the accumulation of biomass and the nutrition provided by zinc in two critical crops. Both plant species increased their biomass when treated with a zinc -GO liquid fertilizer rather than a zinc GO powdered fertilizer. According to the study's findings, mycorrhizal Medicago plants with better zinc uptake had been given zinc -GO powder rather than receiving mock-inoculated aggregate injection [47].

3.5 Antimicrobial effects

Recent research has led to the discovery of several nanomaterials having antibacterial and antifungal properties. These nanomaterials include metal oxide, metalloid, nonmetallic, and carbon nanoparticles. It has been demonstrated that several of these nanomaterials, in addition to giving plants the nutrients they need, also increase the host's resistance to illness. Plants are better able to manufacture a greater quantity of defense compounds with the assistance of nanoparticles. Plants are being treated with nanoparticles to stop the spread of disease [48]. The administration of the potent chelating agent EDTA is what is needed to get the job done when it comes to functionalizing GO. In a dehydration condensation approach, the hydrolysis of the trialkoxy groups led to enhanced cell inactivation of the gram-positive *Bacillus subtilis* and the gram-negative *Cupriavidus metallidurans*. As a result, GO-EDTA appears to be a promising carbon nanomaterial for potential future applications in the medical field [49]. Researchers investigated the effects of 0.1-1 mg of Ag-GO per gram on soil microbial communities. Silver-GO was able to inhibit nitrification by lowering the activity of C-cycling enzymes. According to the findings of this study, the relative abundance of Firmicutes was significantly higher than that of acidobacteria and vyanobacteria. Silver-GO has been demonstrated to be detrimental since it alters the microbial activity in the soil, which is tied to the C and N cycle and the composition of bacterial communities [50]. The researchers utilized Hummer's method to produce flaky GO nanoparticles. This method involved the chemical modification of GO with *Nigella sativa* seed extract before encapsulating it in poly ethylene glycol. The drug delivery strategy was demonstrated to kill *Staphylococcus aureus* and *E. coli* effectively by promoting access to the bacterial nucleic acid and cytoplasmic membranes. This resulted in cell wall breakdown, nucleic acid destruction, and better cell-wall penetration against these two bacteria [51].

4. Challenges in Implementing GO Nanoparticles in Agriculture

4.1 Synthesis

The synthesis of high-quality GO nanoparticles is complex and requires precise control of the reaction conditions. Achieving a consistent and reproducible synthesis can be challenging. The degree of oxidation affects the properties of GO nanoparticles, such as their size, shape, and surface chemistry [52].

4.2 Dispersion

GO nanoparticles tend to agglomerate and form large, irregular clumps in aqueous solutions, which can limit their effectiveness in many applications. Achieving good dispersion of GO nanoparticles is critical to their successful implementation.

4.3 Toxicity

GO nanoparticles can be toxic to cells and organisms, particularly at high concentrations. Understanding the potential toxicity of GO nanoparticles and developing strategies to minimize it is an important challenge. However, the toxicity of GO nanoparticles is still not fully understood, and further studies are needed to elucidate their biological effects.

4.4 Stability

GO nanoparticles are prone to oxidation and degradation, which can limit their stability and shelf life. Developing strategies to improve their stability is an ongoing challenge. However, it is difficult to control the degree of oxidation, as it depends on several factors, such as the type and concentration of oxidizing agent, temperature, and reaction time. The oxidation process can introduce defects in the graphene lattice, such as holes and vacancies, which can affect the mechanical, electrical, and optical properties of the GO nanoparticles. GO nanoparticles tend to aggregate in aqueous solution, due to their hydrophilic nature and strong van der Waals forces. This can affect their dispersibility and stability, which can in turn affect their biological and environmental applications.

4.5 Cost

The cost of producing high-quality GO nanoparticles can be high, particularly when using large-scale synthesis methods. Developing cost-effective synthesis methods is an important challenge in implementing GO nanoparticles in industrial applications.

4.6 Standardization

Due to the complexity of the synthesis and variability in properties, the lack of standardized methods of characterizing and evaluating GO nanoparticles can make it difficult to compare results from different studies and to develop a comprehensive understanding of their properties and potential applications. The synthesis of GO nanoparticles is typically carried out in small batches, which can limit their scalability for large-scale production. Moreover, the cost of production is currently high, which makes it challenging to produce GO nanoparticles at an affordable price. To overcome these challenges, several approaches have been developed, such as using mild oxidizing agents, controlling the reaction conditions, functionalizing the surface of GO nanoparticles, and optimizing their size and shape. However, further research is needed to develop more efficient and scalable methods for the synthesis of GO nanoparticles, and to better understand their properties and applications [53].

5. Large Scale Synthesis of GO Nanoparticles

The large scale fabrication of GO nanoparticle is illustrated in Figure 2. The capacity of multilayer graphite to form complexes lies at the core of today's most cutting-edge methods for GO production. Active metal atoms and specialized oxidation agents can infiltrate the two thin layers of graphene that make up crystallized graphene. This results in an increased effect and changes to the layers of interfaces that include chemically related functional groups. When subjected to the right oxidizing agents, the graphitic crystal will, in the end, disintegrate into its component carbon monolayers, each of which will have undergone a distinct chemical transformation [54]. The GO synthesis methods developed by Hummers, Brodie, and Staudenmaier are the ones that see the greatest use. In each of these three processes, graphite is subjected to strong oxidants [55]. With just around 5 kg of the necessary precursor material, it is possible to create an effective process involving significant amounts of green synthesis from the leaves of *Quercus ilex*. According to the findings, the potassium concentration in its natural environment was 6.15%. This has the potential to be a technique that is both economically helpful and environmentally laudable, with nearly no emissions of a negative kind [56]. Another researcher discussed the oxidation of graphite to form GO; a cation exchange procedure was used to manufacture n-alkylammonium-GO derivatives with alkyl groups of varying chain lengths. These derivatives could then be utilized. In order to investigate the swelling of these compounds, a wide variety of organic solvents and combinations of these solvents were utilized. Using surface excess isotherms, a calculation was made to determine the adsorption capacity of hydrophobized graphite oxide in various liquids [57]. The Hummers method involves reducing exfoliated graphite oxide nanosheets in an aqueous colloidal solution with hydrazine hydrate, which ultimately results in graphite oxide. This step is necessary for the production of graphene. The research indicates that the sp3-hybridized carbons in graphite oxide are converted into sp2-hybridized carbons in graphene, and the average size of the sp2-hybridized carbon layer surface in graphene is larger than that of graphite oxide. Despite this, graphene's crystallization intensity and regularity are lower than those of graphite oxide [58]. Despite many other techniques claim to produce large amounts of graphene oxide, no technique has been able to match the scale of production achieved by Hummer's method. This technique employs an electrochemical process that is environmentally friendly, converting vast quantities of graphite into GO. Several different types of analytical techniques were used in order to profile the GO flakes [59]. Modifications were made to both the rate of the reaction and the heterogeneous catalysts in the beginning in order to improve the effectiveness of graphite oxidation. When heat treatment was used instead of the more usual vacuum drying approach, the amount of time needed to process the graphite was cut by more than half, resulting in a significant time savings [60]. When cutting 2D nanosheets into minuscule 0D nanodots using a top-down process, bottom-up QGD manufacturing is limited, and the quality is uncertain. Bottom-up QGD manufacturing is complicated. To create GO quantum dots for the first time, aphanitic graphite, low-cost graphite that contains numerous tiny graphite nanocrystals with a diameter of around 10 nm, was employed as a precursor. This was the first time such quantum dots had been created. It was possible to create substantial quantities of high-quality GO-QDs without the necessity for high-strength cutting if liquid phase exfoliating aphanitic graphite were used in the production process. By producing these so-called GQD, an output almost four times as high as that of the flake graphite precursor were achieved [61]. It might be challenging to maintain a good quality-to-production ratio when dealing with graphene quantum dots. It is possible to readily decrease oxygenated graphene layers coated with epoxy, hydroxy, and carboxyl groups to manufacture enormous quantities of graphene. This paves the way for creating a wide range of functionalized goods based on graphene. GO may be used in several ways, such as as a carbon-containing sheet in papers and thin films or as a filler in polymer or inorganic materials, to form a range of unique materials with various morphological features [62, 63].

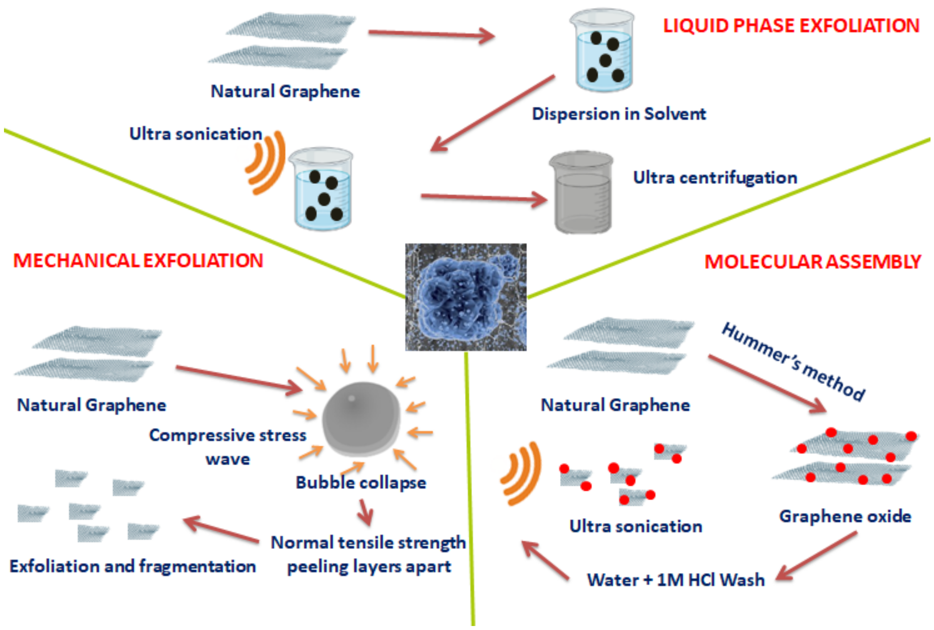

Figure 2. Production of GO nanoparticle – large scale

5.1 Liquid phase exfoliation

Before properly exploiting graphene's properties, a process for its large-scale production is required. Exfoliation and large-scale growth are two fundamental processes [64]. As part of the liquid-phase exfoliation procedure, graphite is typically disseminated in a solvent, exfoliated, and subsequently refined. To make graphene flakes, graphite may be chemically wet dispersed using ultrasonication in organic solvents without any surfactants. Huge strides have been achieved in the last decade since liquid-phase exfoliation of graphene using sonication was first introduced in 2008 [65]. Ultrasonication causes exfoliation by acting on the bulk material with shear forces and cavitation, forming and collapsing micrometer-sized bubbles or gaps in liquids owing to pressure variations. After exfoliating graphene, the inter-sheet attractive forces must be equalized via the solvent-graphene interaction. The best solvents for dispersing graphene are those that reduce the interfacial tension between the liquid and graphene flakes. This is the force responsible for maximising the separation between the two surfaces [66]. The first effect of sonication on GO is the breaking up of huge flakes and the appearance of kink band striations on the flake surfaces, most prominently in the zigzag directions. It is only until fractures emerge along these striations that the tiny graphite strips may be unzipped and peeled off, a process known as exfoliation, and ultimately transform into graphene [67].

5.2 Molecular assembly

Self-assembly is a process through which molecules and nanophase entities may combine or form networks. The approach has become essential in developing contemporary functional materials and devices through different interacting processes of self-assembly, such as electrostatics, chemistry, surface characteristics, and other mediating agents [68]. Most of the self-assembly originates from the self-concentration of GO sheets at liquid-air, liquid-liquid, and liquid-solid interfaces. The peripheral carboxyl groups on GO nanosheets were discovered to interact with quaternized block copolymer chains, causing them to segregate to the water/oil interface. The assembly of GO at the interface and its subsequent confinement causes a jam and eventual buckling if the interfacial area is reduced. Based on the results of a kinetic study of the assembly processes, it was determined that GO diffusion to the interface is the rate-limiting phase [69].

6. Future Prospects

A revolution in agriculture is being fueled by nanotechnology [70]. Although the use of graphene-based nanomaterials in agriculture has received much attention [71]. To enable the use of graphene-metal oxide nanohybrids in a variety of applications, a large-scale, economically scalable manufacturing method is needed. Creating graphene nanostructures from substances like graphite and its oxides requires costly or potentially dangerous chemicals, including hydrazine monohydrate. Additionally, cutting huge graphene domains into smaller ones requires much effort and time [72]. A possible method for producing graphene on a wide scale is the oxidative exfoliation of graphite. Conventional oxidation of graphite effectively speeds up the exfoliation process. Still, the process of turning exfoliated GO into reduced GO emits hazardous fumes and calls for labor-intensive cleaning and reduction processes [73]. Researchers from the University of Manchester are now developing a novel idea in England called "Graphene City," which involves building graphene-related supply chains and introducing graphene products into all domains of everyday life. Furthermore, the graphitization of agriculture is one of their study objectives. To purportedly eliminate waste of energy and space by boosting vertical farming, they are now creating an alternative to agriculture that they have termed "GelPonic". It is claimed that the graphene hydrogel "GelPonic" can "sense" the dietary requirements of plants in the soil and provide them [74]. An in-depth understanding of scaling up nanomaterials can open new avenues toward improving crop practices and agronomic productivity.

7. Conclusions

In conclusion, it is only through the collaboration of experts in agronomy, chemistry, plant physiology, material science, ecology, and toxicology that viable nano-enabled solutions may be developed. In order to make most of the absolute convergence, it is necessary to combine several other vital scientific fields including biotechnology, data storage, data sciences, intelligent systems, and broad social sciences. Creating goods in large quantities at an affordable price is still a distant goal. There has not been enough effort to develop new ways of synthesis that can fully meet the demand of possible applications. The purpose of this current request is to investigate methods of synthesis that are both effective and efficient. The future trends will see the advancement of analytical techniques such as solvent-free synthesis. Some of these techniques involve producing other 2D materials, synthesizing novel GO-based nanocomposites or combining other nanoparticles with uniform properties, and recycling relatively undiscovered industrial effluents to produce composite functionalities quickly. In addition, future trends will see the combination of other nanoparticles to produce composite functionalities. In this way, GO in the right amounts can be used to help plants and crops grow, and it has a lot of potential for use in systems for growing plants and crops.

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