CURRENT PHARMACEUTICAL LETTERS AND REVIEWS (CPLR)

Available online on http://www.cplr.in/

Review Current Pharmaceutical Letters and Reviews 2024; 01(01); 11-24

Green Biomaterials from plants: Harnessing Nature for Sustainable Solutions

Subham Mandal, Suraj Mandal*

B.Pharm Scholar, Department of Pharmacy, IIMT College of Medical Sciences, IIMT University, O-Pocket, Ganganagar, Meerut, 250001, U.P., India

Assistant Professor, Department of Pharmacy, IIMT College of Medical Sciences, IIMT University, O-Pocket, Ganganagar, Meerut, 250001, U.P., India

ABSTRACT

The developing matter of biomaterials derived from plants and its significance in giving sustainable solutions. These biomaterials can decrease ecological harm and the utilization of petrol subordinates by utilizing nature's bountiful assets. Despite the fact that plants can create life-saving therapeutic proteins (like Elelyso TM for Gaucher's contamination, ZMapp TM for against Ebola antibodies, Covifenz TM for SARS-CoV-2 virus-like atom vaccination, and intermittent flu inoculation), making these proteins accessible for public buy can be trying for arranging gatherings. The conclusion of Medicago Inc., a Canadian biotech organization that produces Covifenz, one of the business chiefs, because of the parent organization's withdrawal of hypothesis brings up the issue: What is forestalling the utilization of plant-based biologics to propel wellbeing? This review investigates the regular modern office capability of plants and updates plant-derived biologics (PDB). Highlighted are progressed plant-based expression strategies and state of the art improvements that work with mind boggling protein-based biologic synthesis. The versatility of plant-derived biologics in agribusiness, industry, and human and creature government assistance is highlighted. This appraisal additionally cautiously assesses the managerial worries related with biologics acquired from plants, highlighting contrasts from biologics created in different systems.

Keywords*: Green Biomaterials, Plants, Harnessing Nature, Sustainable Solutions, Plant-Derived Biologics, Application, Antimicrobial agent, Biogenesis, Green Synthesis, Plant Extract, Plant-Derived Biologics*

Received: *25-05-2024 / Revised: 23-06-2024 / Accepted: 03-07-2024*

Corresponding Author: *Suraj Mandal*

Email: *sk8006721807@gmail.com*

Conflict of interest: *Nil*

This is an Open Access article that uses a funding model which does not charge readers or their institutions for access and distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0) and the Budapest Open Access Initiative (http://www.budapestopenaccessinitiative.org/read), which permit unrestricted use, distribution, and reproduction in any medium, provided original work is properly credited.

1. INTRODUCTION

In this period of expanded natural mindfulness, exploring sustainable options in contrast to ordinary materials has become fundamental. Green biomaterials produced using plants have arisen as a positive marker en route, showing the way of thinking of using nature's genuine limit with respect to long haul solutions. These biomaterials, which come from limitless plant assets, enjoy numerous upper hands over their partners made from non-sustainable power sources. Specialists and organizations might relieve the impacts of asset consumption and petroleum product side-effects by using the immense library of plant resources, making way for a more sustainable future [1].

The central likeness of green biomaterials to the patterns of nature lives at their center. Biomaterials produced using plants have the striking skill to biodegrade and reintegrate into the organic system, rather than materials produced using petrol subordinates, which add to ecological change and regular defilement. Due to its natural biodegradability, normal resources are observed, contamination is restricted, and the load on landfills is diminished. Furthermore, the interminable stock of plant assets guarantees a continuous stock organization liberated from the limitations of limited possessions, cultivating long haul viability [2].

Green biomaterials' flexibility reaches out past their inborn advantages to envelop an expansive scope of purposes in a few fields. The potential applications are immense and changed, going from packaging materials that give biodegradability and excrement ability to advancement materials that address the essential dependability of plant strands. With regards to materials, filaments starting from plants, like cotton, hemp, and bamboo, are progressively decided because of their strength and solace. Additionally, in the field of biomedical plan, research is being finished on plant-based polymers to decide their biocompatibility and potential for use in tissue designing and medication conveyance systems [3].

Besides, the advancement of green biomaterials adjusts to moving buyer inclinations for harmless to the ecosystem items. Developing demand for items that exemplify reasonability all through their lives is a consequence of the expanded spotlight on moral utilization and regular obligation. Thus, endeavors are restricted in their capacity to make and put resources into the progression of green biomaterials to fulfill the market's developing necessities while limiting their organic effect [4].

Plant-based green biomaterials answer a change in thinking toward a sustainable course of occasions that coordinates improvement and ecological administration. Through the use of advances in materials science and biotechnology, alongside the inborn characteristics of plants, we can make an abundance of harmless to the ecosystem options in contrast to traditional materials. We are preparing for a more sustainable and harmless to the ecosystem future where the abundance of nature fills in as motivation for headway as we proceed to study and work on these biomaterials [5].

1. PLANTS-DERIVED BIOLOGICS: TYPES

Plants can be used as an expression system for a specific range of particles that are covered by biologics based on proteins obtained from plants. As a rule, they have very mind-boggling structures with extra parts (unsaturated fats and glycocarbohydrates). They can be classified into a couple of key gatherings, including vaccines, monoclonal antibodies (mAbs), receptor modulators, enzymes for substitution treatments, and bioactive little particles. The different scope of recombinant proteins uncovered plants' true capacity as adaptable conveyance systems for recombinant proteins [6].

1.1. Partitions of Antibodies and Antibodies

Transplantation systems based on plants have been utilized to convey vaccination segments and monoclonal antibodies, or "plantibodies." During the Ebola outbreak, for instance, the plant-based production of ZMapp, a mixed beverage containing monoclonal antibodies, effectively increased the rate of survival for infected patients; nevertheless, the small number of patients treated complicates an accurate assessment of survivability. Plantibodies are supposed to give benefits as far as lower creation expenses, flexibility, and personalization [7].

1.2. Vaccines and VLPs

Plants offer a viable platform for the development of vaccines due to their ability to transmit immunogenic viral and bacterial antigens as well as highly structured particles (VLPs). Since VLPs are self-gathering viral coat proteins and don't contain genetic material, they can be utilized to make vaccines and nanoparticles. Plant-derived VLPs and creative VLPs are utilized as resistant system illnesses, awareness's, harmful growth, and viral contaminations as well as immune modulators and self-adjuvants. These vaccines have advantages, for example, lower creation costs, further developed security, unimportant prerequisites for the viral chain, and oral organization. In non-industrialized nations, eatable vaccines that transport neutralizer antigens through plants with regular plan hold more noteworthy commitment for immunization conveyance. By and by, limiting the immunization segment is a grave treachery. Also, VLPs can be utilized as nanoparticles in medicine conveyance systems [8].

1.3. Therapeutic Enzymes

Recombinant enzymes with created therapeutic qualities are delivered by plants, like Elelyso TM (β-glucocerebrosidase), which has terminal mannose stores and is a fundamental impetus swap treatment for Gaucher's disease treatment. Pegunigalsidase alpha and insulin created from plants have shown guarantee in preclinical and clinical testing. Enzymes derived from plants can be managed orally because of the non-degradable cellulose wall. The plant cell wall is isolated by commensal microorganisms in the gastrointestinal epithelium, which then, at that point, conveys bioencapsulated recombinant proteins that trigger an adaptable, safe response. When contrasted with customary biologic improvement strategies, the utilization of plant expression systems conveys a normal choice and various benefits. It likewise modifies the wellbeing of humans and different creatures by the viable synthesis of befuddling recombinant proteins [9].

1.4. Modulators of Receptors

Plant-based expression systems have demonstrated to be an effective method for delivering a few little polypeptides and glycoproteins associated with administrative capabilities inside mammalian cells, like hormones and cytokines. Human growth hormone (hGH) regulated in N. benthamiana plants demonstrated its predictable portability in a hypophysectomized critter. Hailing proteins called cytokines assist with managing irritation in the body and are utilized in the therapy of malignant growth, neurological issues, and other related sicknesses. Utilizing different strategies to build the yield and strength of recombinant proteins, a few plant animal groups have been presented to erythropoietin, IL-2, IL-4, IL-12, IL-13, IL-18, cardiotrophin 1, human (GM-CSF), (TNF), interferon-alpha, human fibroblast growth factor 8b, and insulin-like growth factor 1 [10].

1.5. Small Molecules

Triterpenoids, alkaloids, and phenolics are among the helpful blends that are distinctively tracked down in plants and are coordinated through complex biochemical courses. The low yields and inciting of neighbourhood species make the extraction of these blends costly [11]. To defeat these difficulties, specialists have zeroed in on an exact portrayal of the biosynthesis courses for metabolites derived from plants, determined to repeat these pathways in other more controllable natural elements by co-communicating significant enzymes. This technique likewise considers the generation of variations of particles that are usually conveyed by combinatorially communicating various enzymes. The biosynthesis pathway for the counter malarial synthetic artemisinin was reproduced in yeast and thusly moved to different creatures, for example, more manageable plants like N. benthamiana, to act as an illustration of this technique. This approach has been utilized to make sense of the biosynthesis of paclitaxel and vinblastine, two anticancer medications [12].

1.6. Bioactive Proteins from Plants

Additionally, biologics derived from plants enclose bioactive particles like lectins. Customary proteins known as lectins have the ability to bind quite varied carbohydrates to the sugar groups of various particles. Certain lectins exhibit potent antimicrobial activity by limiting their binding to sugars on microbial surfaces and causing changes in pore formation and cell sensitivity. Because of their inherent properties, they are useful as adjuvants for antibodies, microbicides, and anticancer drugs. Mistletoe lectins (ML-I, ML-II, and ML-III), which demonstrated anticancer motility, were briefly delivered by N. benthamiana [13].

2. SWOT ANALYSIS OF BIOLOGICS: STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS

Biologics generated from plants have a lower immunogenicity and security profile, which increments patient opposition and lessens unfavourable impacts. Plant glycan moieties have been generally remembered to be immunogenic; the fucose structures are believed to be cross-responsive starch determinants. Protalix, a plant-derived taliglucerase alfa (TGA), has a development of xylose and fucose, which is found in tri-mannose glycoform and makes up over 90% of the complete glycan pool. In a clinical preliminary including sound human members, no clearly unsafe impacts were noticed, and no enemy of medication antibodies were found [14].

In whole plants and plant cell suspension societies, it makes sense to supervise biologics orally with little to no cleaning. The ability of plant cell walls to protect the biologic from enzymatic degradation in the gastrointestinal tract and to reach the lymphoid tissue of the stomach in its dynamic form may result in oral resistance, the avoidance of undesired safe responses, and easily impacted responses [15].

These biopharmaceuticals' creative turn of events and adaptability offer a critical chance to tackle the increasing expenses of medical care and provincial varieties in admittance to fundamental physician endorsed drugs. As a result of their remarkable flexibility, plant-based biologics can be exactly modified and fitted to meet various therapeutic necessities. Through the inborn flexibility of plants, scientists can introduce another period of customized medication, wherein endorsed regimens are custom-made to the particular necessities of every patient, working on therapeutic results and propelling the general understanding of thriving [16].

Table 1: SWOT analysis of biologics obtained from plants [17].

Strengths	Weaknesses
Low cost: In comparison to alternative expression methods, plants can be produced for comparatively little money. Recombinant protein production can be profitable if it is high, downstream processing can be well handled, and there is a chance to temporarily increase production.	Time consuming: Plant-derived biologics can be produced via a lengthy process.
Scalability: It is simple to scale up plant-based biologic manufacturing to satisfy demand.	Variable yields: Plant-derived biologics can have very different yields.
Complex molecules: Complex biological compounds with	Regulatory considerations: Biologics

post-translational modifications can be produced by plants.	generated from plants must receive regulatory agency approval and are subject to regulatory monitoring.
Safety: Biologics derived from plants are thought to be safe for ingestion by humans and do not provide a risk of contamination.	Protein degradation: Plants have proteases, which can break down proteins as they are being produced.
Opportunities	**Threats**
Alternative to traditional expression systems: Biologics generated from plants have better clinical outcomes.	Intellectual property: Development and commercialization may be impeded by intellectual property rights.
Unmet medical needs: Biologics derived from plants can help with unmet medical requirements, such affordable vaccinations for underdeveloped nations.	Competition: Plant-derived biologics is a fiercely competitive area.
Diversification: Utilizing biologics obtained from plants broadens the sources of biological output.	Public perception: Plants that have undergone genetic modification may encounter resistance.

3. PRODUCTION SYSTEMS BASED ON PLANTS ARE MANUFACTURED

Many of the fundamental, specific drawbacks of PMF have occasionally been overcome, such as low yields, the unfavorable recovery of recombinant proteins during downstream handling, and the impact of obvious glycosylation in plants. Agrobacterium entrance, transient expression, plant cell social orders, stable plastid change, plant genome editing for further developing plant biosynthetic pathways, expanding protein trustworthiness, and the improvement of current Good Manufacturing Practice (cGMP) are only a couple of instances of the progressions that will prompt an ascent in the creation of uncommon, helpful recombinant proteins in plants. Figure 1 presents the vital stages in the improvement of PDB [18].

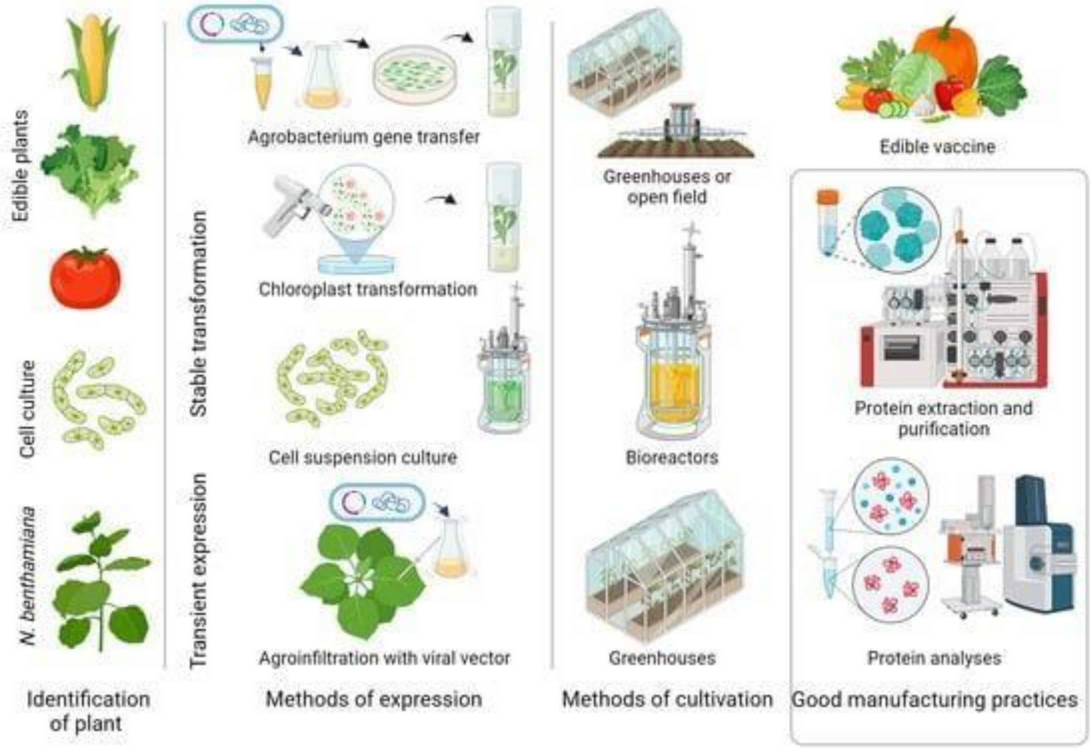

Figure 1: key processes in plants that produce biologics [19].

The variety of plant species, which incorporates lettuce, tomato, carrot, tobacco, maize, rice, potato, and potato, has prompted the progression of different plant development methods. Plant cell culture systems such as ProCellEx® and tobacco cell social orders (BY-2 and NT-1) have received support from the FDA and USDA due to their regulatory uniformity, high yield, precise climate control, and innovative manufacturing methods. Plant cell suspension social orders link the stages of business cell-based formation with plants. Other plants that are used in medicinal protein cell suspension systems include Chlamydomonas reinhardtii, Lemna minor, and Physcomitrella patens [20].

Nicotiana benthamiana, a tobacco cousin, is often used in molecular farming to transport recombinant proteins through transient expression. This kind of plant is suitable for transient expression through the use of plant virus-based vectors and agrobacterium attacks. Only the portions of the viral genome required to induce protein expression are present in deconstructed vector systems; these segments account for up to 80% of total soluble protein production. Qualitative expression variations drive the aggregation of multi-subunit proteins such as VLPs, IgA, and IgM [21].

Planned post-translational alterations, such as glycosylation anomalies and the expression of recombinant glycosylation enzymes, have been developed for the legal production of recombinant glycoproteins. Through the application of innovative techniques, such as CRISPR/Cas9 genome editing, the endogenous N-glycosylation machinery of plants has been engineered, resulting in N. benthamiana, which requires the movement of both α-1,3-fucosyltransferase and β-1,2-xylosyltransferase.

Table 2: a comparison of the various techniques used to produce biologics derived from plants [22].

Method	Description	Advantages	Disadvantages
Stable nuclear transformation	stable incorporation of the desired gene into the plant's genome, allowing for reliable and continuous protein production over time. Transgene delivery using agrobacterium or biolistics.	Possibility of extensive output. Ideal for biologics that are in high demand or that need sophisticated PTMs. the utilization of grains for long-term preservation at room temperature and edible plant species for oral administration.	the laborious process of plant regeneration and change. somewhat reduced yield of protein. Gene silencing and location effect potential. GMO-related regulatory issues and public concerns.
Stable chloroplast transformation	The 10,000 copies of the chloroplast genomes found in each plant cell are capable of stably integrating the desired gene through a biolistic mode of delivery.	There is no evidence of gene silencing, and it is possible to express hazardous proteins effectively. The recombinant protein can be expressed at very high levels, up to 45% of the total protein. There is no gene flow and many genes that can be expressed simultaneously, which helps produce complex proteins.	Recombinant protein purification is a laborious procedure that involves low transformation frequencies, inclusion body formation, and difficulties. The regulatory aspects.
Viral Vectors	using viral vectors, such TMV or CPMV, to take advantage of the plant's viral replication machinery in order to increase the levels of protein expression.	higher yields of proteins than with non-viral expression techniques. compatibility with approaches to stable and transient expression.	Possibility of viral contamination and related biosafety issues. For the development and handling of viral vectors, additional processes are needed. Possibility of negative impacts on plant growth.
Transient Expression	Target proteins can be produced quickly by introducing the desired gene into plants by viral, agroinfiltration, or binary vector-based plasmids.	Rapid and abundant synthesis of proteins. Ideal for situations requiring quick reactions. adaptability and versatility with regard to the kinds of biological molecules that can be generated.	For ongoing production, plant agroinfiltration must be repeated due to the temporary nature of expression.
Plant cell cultures	Recombinant protein synthesis in suspension cultures of plant cells.	Possibility of simple scaling up for aseptic production employing traditional fermentation techniques. minimal chance of contamination. the same legal specifications as systems used to produce mammalian cells.	Compared to bacteria and mammalian cells, it grows more slowly and yields less; the total cost is medium. Heterogeneity is a characteristic of plant cell cultures.
Hairy roots	Recombinant protein rhizosecretion in a hydroponic	enhanced product homogeneity, easier purification, and protein	High proteolytic activity, protein breakdown, and regulatory issues

	environment.	secretion into the medium.	surrounding GMOs.
Gene Editing	precise genome editing of plants through the use of gene editing tools like CRISPR/Cas9 in order to maximize protein production and minimize proteolytic degradation.	precise gene or regulatory element alteration to improve protein expression. Possibility of multiplex gene editing to enhance several features at once.	Genetic editing experiments demand a high level of technical intricacy and optimization. Possibility of unwanted genetic alterations and off-target effects. GMO regulatory considerations.
Glycoengineering	To supply the necessary particular glycans, undesirable glycan alterations must be removed and glycosylation enzymes must be expressed.	creation of human-type glycan-containing recombinant glycoproteins that mimic natural glycosylation. Remove any unwelcome glycosylation alterations.	Some plant species are intolerant to the dangers associated with genetically modified organisms (GMOs), N-glycan heterogenicity, and glycan processing pathway modification.
Downstream Processing	application of purification techniques to efficiently eliminate pollutants unique to plants, guaranteeing the stability and caliber of the finished product.	enhanced purity and elimination of undesired pollutants unique to plants. downstream processing optimization for particular biological compounds.	Extra criteria, expenses, and procedural stages. specialized purification techniques are required for many biological substances.
Formulation and Delivery	creation of novel formulations and delivery techniques to enhance the stability, bioavailability, and focused distribution of biologics generated from plants.	increased stability when being transported and stored. increased effectiveness and bioavailability in the target cells or tissues. delivery that is intended to reach particular organs or cellular divisions.	Extra expenses related to delivery and formulation processes. Possible obstacles to reaching targeted delivery to particular locations.

4. CHALLENGES IN MAKING AND USING BIOLOGICS DERIVED FROM PLANT

4.1. Expression of Complex Proteins

Plants have complex strategies for compacting and collecting data, which makes it hard to create confounding proteins at a high level. There are two methods for moving different recombinant proteins in plants: co-change with explicit kinds of Agrobacterium and generation of shifted recombinant qualities. Since complex recombinant proteins associate with glycosylation and breakdown during the secretory pathway, they will quite often collect more in the apoplast or endoplasmic reticulum. Contrasted with the cytosol, proteolytic exercises at these destinations are less powerful. It has been suggested that protein breakdown and collection can be improved by co-expressing recombinant proteins with chaperones that have comparable starting positions. The trama focus pressure response was affected by co-expression of the human chaperone calreticulin (CRT), which increased the protein product of the HIV-1 antigen and other viral glycoproteins. Regardless, there is no comparable effect when SARS-CoV-2 RBD glycoprotein and human CRT are conveyed simultaneously. Adapting plant-based expression systems to these intricate protein architectures is a major test [23].

4.2. Post-Translational Modifications

Numerous biologics rely upon post-translational modifications (PTMs) for their practicality and use. By the by, it's conceivable that PTMs found in plants and those found in mammalian systems are basically something similar. Recombinant glycoproteins, for example, xylose and focus fucose, are intricately N-glycosylated by plants; in any case, they require pathways for galactosylation, sialylation, focus fucosylation, and bisecting GlcNAc. Part of the intrinsic qualities of recombinant glycoproteins (immunogenicity, security, and) not entirely set in stone by the sort of glycan that is available in them. It is enticing to adjust plants' regular N-glycosylation apparatus to represent the development of complicated N-glycans. CRISPR/Cas9-mediated knockout development can be utilized to meet disregarded objectives in N-glycan planning. Creating procedures to further develop PTM adherence in plants is a vital errand [24].

4.3. Post-Translational Gene Silencing (PTGS)

Restricting the host plant's RNA silencing pathway is an extra strategy for accomplishing high measures of recombinant protein creation. Arabidopsis thaliana monstrosities (sgs2 and sgs3) were used to achieve extraordinarily high-level transgenic expression of the β-glucuronidase (GUS) gene using checked calmed PTGS. By using RNA interference (RNAi) technology, which includes silencing the DCL2 and DCL4 genes, the production of recombinant proteins in N. benthamiana was further enhanced. With the use of the CRISPR/Cas9 discovery, the RDR6 gene and ago2 in N. benthamiana were successfully removed, which led to an increase in the production of recombinant proteins [25].

Furthermore, the expression of recombinant proteins can be supported by co-expression with gene silencing silencers such as P19.

4.4. Recombinant Protein Degradation via Proteolytic Process

A huge swath of dynamic endogenous proteases is available in plant cells, carrying out routine cell roles while establishing a climate that is destructive to the recombinant proteins. Plant recombinant proteins are known to be proteolytically debased by a couple of proteases. Protease development can be inhibited by co-expressing protease inhibitors and pH regulators, or by using protease gene knockout/knockdown technologies like as CRISPR/Cas9, TALEN, and RNAi [26].

4.5. Processing Downstream

Plant-derived biologics can be hard to actually purify and handle downstream because of the consideration of plant-unequivocal unfamiliar mixtures like polysaccharides, varieties, and phenolic blends. Moreover, issues relating to biologics' major uprightness and sufficiency rely upon their essential multifaceted nature. Various types of debasement, like amassing, isomerization, hydrolysis, deamidation, and oxidation, are adequate to biologics. Creating powerful and serviceable disinfecting procedures that match the biologics' hidden reliability and natural function is fundamental.

Table 3: Overview of Studies on Bio-Based Sustainable Solutions

Authors	Subject	Result
Tanvir et al. (2021) [27]	Using phototrophic microbes to harness solar energy	Phototrophic microbes' versatility in producing bioenergy, synthesizing biomaterials, and providing environmental solutions
Edrisi et al. (2022) [28]	Utilizing biomaterials from terrestrial crops and sequestering carbon	Techniques to improve the use of biomass, carbon sequestration, and circular economy concepts
Pradhan et al. (2020) [29]	creation of useful biodevices from materials found in nature	investigation of natural materials for wearable electronics, environmental sensors, and biomedical devices with a focus on biocompatibility and environmentally friendly manufacturing techniques
Iravani and Varma (2019) [30]	Tissue engineering using plants and plant-based polymers as scaffolds	Many and varied plant-derived materials with an emphasis on biodegradability, biocompatibility, and environmentally friendly processing techniques for tissue engineering applications
Karimi-Maleh et al. (2023) [31]	Per- and polyfluoroalkyl substances (PFAS) elimination with biomaterial substitutes	Creative methods for removing persistent flame retardants (PFAS) with biomaterials that address health and environmental issues, explain how PFAS adsorb and degrade, and have the potential for large-scale use
Bell et al. (2018) [32]	The goal of the European Union is to become the global leader in the bio economy.	Examining the EU's strategy framework for bio economy advancement and the policies, investments, partnerships, and projects that support sustainability, innovation, and economic expansion.

5. GREEN PLANT EXTRACT NPS SYNTHESIS

The creation of green nanoparticles (NPs) is an area of developing interest for researchers, physicists, and specialists alike. Metal NPs can be delivered by plants from various metal salts, remembering those found for plastic, proteins, flavonoids, phenols, alcohols, and fragrance. Biogenesis protects the environment from pollution by using auxiliary metabolites such as alkaloids, flavonoids, saponins, phenols, proteins, starches, glycosides, quinine, steroids, and tannins. Natural mixtures have the ability to diminish and settle metal particles while improving the plan of nanoparticles [33].

The grouping of metal salts, the amount of biomass or plant extract, and the pH and temperature of the action zone are basic cutoff points in the biogenesis of nanoparticles. Research has zeroed in on the recognizable proof of delicate sums and the development of plant-mediated NPs. By and by, just couple of studies have examined unconstrained synthesis with isolated atoms. Apigenin, derived from henna, is utilized to move silver and gold nanoparticles through electrostatic communication with carbonyl gatherings. After being separated from the leaf bloom's leaves, phytollanthin was used in another process to produce gold and silver nanoparticles.

Plant phytochemicals and the course of action's gathering of metal salts impact metal reduction and change. The two stages of NP creation are nucleation and particle growth, which requires the decrease and equilibrium of normal iotas. The course of nucleation includes responding with a forerunner that contains a metal salt by treating metal salts with plant extract. At the point when flavonoids respond with metals, they structure tautomeric edifices, which change their enol structure into a keto structure. Silver molecule decline has been connected to cell reinforcements such ascorbic acids [34].

The synthesis of nanoparticles derived from plants is more secure, lighter, quicker, planned at low temperatures, takes less assets, and represents no effect on ecosystem parts. As individuals' interests about the environment develop, it has acquired expanding consideration. Using plants to produce NPs has several advantages, including cleaner solvents, fewer hazardous chemicals, easier reaction conditions, sensitivity, and suitability for use in clinical, cautious, and pharmacological applications.

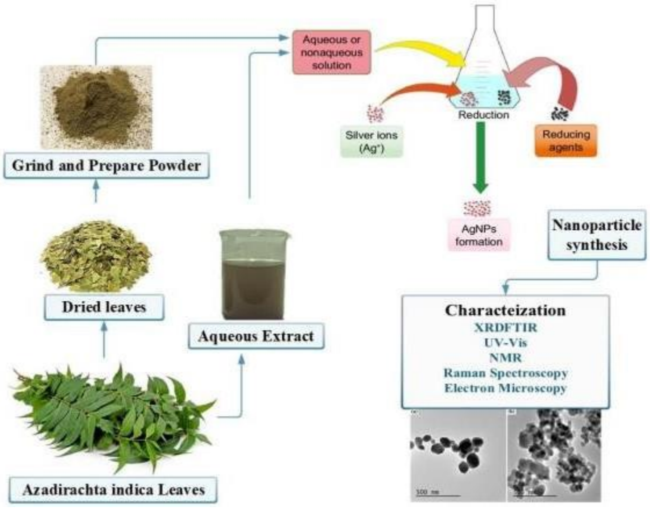

Figure 2: Steps involved in the green manufacturing of nanoparticles [35].

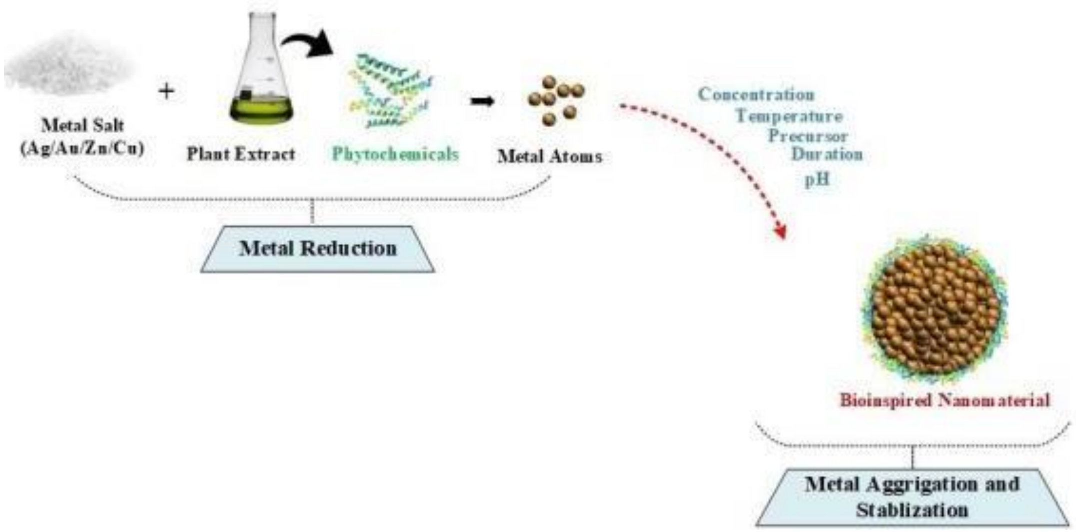

Figure 3: The mechanism of reduction and capping by flavonoids is a theory [36].

5.1. Plant-Mediated Biosynthetic Synthesis

Microorganisms are fit for delivering an extensive variety of momentous nanostructures. Along these lines, researchers are presently substantially keener on coordinating nanostructures for different purposes using these animals. Minute organic entities and parasites can deliver inorganic particles through unconstrained synthesis that is set off by regular occasions. It is feasible to shape wanted calculations and bits of nanostructures by dealing with the natural synthesis. Regardless of the exactness of the physicochemical synthesis of nanoparticles, the natural synthesis of nanoparticles is as yet restricted concerning cycle adaptability and particle math controllability. Furthermore, normally propelled synthesis offers an extensive variety of synthesis choices and has empowered specialists to consolidate inorganic nanoparticles utilizing customary metal forerunners [37].

- **From Leaf**

Plants rely on their super parallel limbs, called leaves, for photosynthesis, transpiration, and guttation. They create phytochemicals and bioactive blends for plant defense, which aid in the definition of "green" nanoparticles (NPs). Moreover, plants create difficult-to-isolate NPs on their own leaves by metal salt aggregation on the ground. The creation of NPs has been attributed to the use of leaf extract, with specific emphasis on the leaves of P. nigrum, Alternanthera sessilis, Centella asiatica, and Murrayakoenigii.

All plants have seeds, which have an outer covering and play a fundamental role in the process of multiplication. Essential to the biocreation of NPs include proteins, polyphenols, supplements, and other bioactive combinations. Seeds of Sinapis arvensis have demonstrated an ability to inhibit the growth of N. parvum's mycelium by more than 83%. Flavonoids and other typical bioactive components found in fenugreek seed extract, such as lignin, saponin, and nutrients, function as surfactants and buffers against chloroauric corrosive agents.

Xu et al. (2014) [38] integrated silver nanoparticles (NPs) with a measurement of 25-35 nm utilizing grape seed extract. A few ocean pathogenic minute species were tried for their capacity to hinder the growth of microbes.

The kind of NPs essentially affects how successful AgNPs are as an antibacterial agent. Alfuraydi and partners delivered roundabout molded SCAgNPs with a measurement going from 6.6 nm to 14.8 nm derived from Sesamum indicum, L. A human chest infection cell line was exposed to a cytotoxicity investigation utilizing two unmistakable SCAgNP focuses (2.5 and 7.5 g/mL).

- **From Flowers**

Different phytoconstituents tracked down in flowering plants, like alkaloids, flavonoids, phenols, saponi, steroids, and tannins, have antibacterial, anticancer, and disease counteraction properties. The improvement of microparticles (MNPs) derived from plants upgrades feasibility in more modest amounts. The flower extract of Rhanterium papposum yields silver, zinc, and gold nanoparticles (NPs), which are powerful antifungal and cytotoxic agents. The high starch and protein content of Rose hybrida petal extract was utilized by Noruzi et al. (2011) [39] to generate 10nm AuNPs. Padalia et al. (2015) [40] demonstrated the bactericidal effects of AgNPs against Gram-positive and Gram-negative organisms through the bio-debasing of AgNO3 using an extract from Tagetes erecta blossoms. Consolidating Catharanthus roseus and Clitoriaternatea blossoms has exhibited the intensity of MNPs against pathogenic microorganisms as well as their restorative characteristics. A green science technique was utilized to make gold nanoparticles utilizing nyctanthesarbortristis. Mirabilis jalapa sprouts were utilized to deliver AuNPs estimating 60-70 nm.

- **From Root**

To make AgNPs, investigators have utilized an assortment of plant extracts, like sucrose, coumarins, alkaloids, quinones, tannins, steroids, saponins, polysaccharides, and flavonoids. 10 to 15 nm round AgNPs were made utilizing root extract from Alpinia calcarata, and these NPs exhibited cytotoxicity against different illness cell lines. Comparative phytoconstituents are found in Berberis asiatica root extract. These AgNPs have been demonstrated to be hepatoprotective, antimicrobial, hostile to diabetic, and loosening up agents. They are utilized to treat various ailments [41].

HRTEM was utilized to zero in on the morphologies of AgNPs while utilizing watery root extract of Alpinia calcarata as a diminishing and settling agent. Utilizing Fourier change infrared spectroscopy and (ICP-OES), the parts of the extract were distinguished. The plant Erythrina indica was utilized to make round AgNPs that went in size from 20 to 118 nm. In Indian customary medication, asparagus race mosus was believed to be helpful for working on in general wellbeing and mending resistant issues related with pressure.

- **From Fruits**

Fruit NPs are made from the mature ovaries of flowering plants and include minerals, nutrients, enzymes, phenolic acids, carotenoids, protein, and fat. The antibacterial, reactive, anticancer, and cancer-prevention agent qualities of these NPs have been demonstrated. Roughly 600 fruit carotenoids are plant pigments that have red, yellow, and orange colors. Nearly 4000 fruit flavonoids have been identified as including flavonoids, phenolic compounds with anthocyanins, flavanones, catechins, flavanols, flavones, and isoflavones. Fruits also contain optional and necessary metabolites. Plant fruit extracts are typically used in the production of green nanoparticles. Research has indicated that increasing the fruit extract's centralization reduces AgNP size and increases their antibacterial activity. Gnanajobitha et al. (2013) [42] demonstrated the production of circular-shaped AgNPs with hindrance zones against K. planticola and B. subtilis in a concentrate.

- **From Gum**

Gum is a polysaccharide-based substance found in woody plants that is administered in response to radiation and insect damage. It has antibacterial, antispasmodic, anticancer, and arrhythmia exercises and is used in traditional medicine. To create green MNP, several plant gum extracts have been used as an adjusting and bio-diminishing agent. Kora et al. (2012) [43] used gum ghatti (Anogeissus latifolia) as a settling and decreasing agent for 5.7 0.2 nm circular AgNPs. Alharbi et al. (2016) [44] incorporated round-shaped AuNPs that essentially stimulated mitotic division and dust germination using Terminalia arjuna gum extract. Baranwal et al. (2018) [45]categorized the nanostructures using various techniques and enabled GNiOc for nitroarenes decline with sodium borohydride by using guar gum (GG). Gum extracts from Salmalia malabarica, Styrax benzoin, and Anacardium occidentale L. also demonstrated bactericidal activity against both Gram-positive and Gram-negative tiny organic entities.

- **From Stem**

A plant's stem rises above the ground to fulfill a variety of functions, such as support, water circulation, capacity, food conveyance, and abiogenetic growth. It includes a variety of useful groups and significant optional metabolites, such as phenolic, amine, and carboxyl intensifiers that contribute to the reduction of metal particles during nanoparticle interaction. The redox association is continuously bonded to these metabolites in order to form naturally satisfying nanoparticles. It has been demonstrated that biosynthesized nanoparticles can efficiently check for oxidative tension, genotoxicity, and changes connected to apoptosis. AgNPs were produced by using a methanolic extract of Callicarpa essential gayi stems; the conversion of silver particles into metallic AgNPs was facilitated by the aldehyde pack. AgNPs with widths ranging from 7 to 50 nm and 9 to 30 nm were generated by Paul Kumar et al. (2014) [46] Green from the leaves and stems of Woodwind player nigrum, and their antibacterial efficacy against agrarian plant illnesses was evaluated. Garcinia mangos tana watery stem extract was used as a reducing agent. AgNPs were thought to be quite effective against E. coli and B. subtilis bacterial strains.

- **From Bark**

The outermost tiers of woody plant stems and roots, known as bark, have the ability to control the flow of water and are rich in minerals, carbohydrates, proteins, saponins, polyphenols, and other bioactive compounds. Barks' ability to strengthen cells makes them useful for flavoring and medicine. Yugandhar et al. (2015) [47] used Syzygium alternifolium, a flavorful and aromatic plant with anti-cancer and moderating effects, to organize silver nanoparticles. AgNPs with widths ranging from 10 to 80 nm were created using Afzeliaquanzensis bark extract, and they demonstrated strong antibacterial action against S. aureus and E. coli. AgNPs that were mediated by the bark of Solanum trilobatum also demonstrated strong antibacterial qualities.

- **From Rhizome**

Rhizomes, a subterranean stem that gives rise to extrinsic roots and horizontal branches, are modified for food storage and have naturally occurring dynamic mixes that promote restorative qualities. Rhizomes of Curcuma longa, a plant prized for its healing qualities, store curcumin. Nanocucumin, an AgNP based on curcumin, was assembled by Hettiarachchi et al., (2021), [48] and used in a cytotoxicity study. To create AgNP, Bergenia ciliata (BC) was used, and standard procedures were followed to evaluate the material's antibacterial and cytotoxic qualities in vitro. Various rhizome extracts, such as Dryopteris vile irhizoma, were employed to initiate the biosynthesis of AgNPs. Utilizing the integrated AgNPs, antibacterial activity against several bacterial strains was studied in order to identify significant cell disruption. Several Drove light sources were used to examine the AgNPs' bactericidal properties. In green light-intervened AgNPs, the zone of restraint against B. cereus was thought to be particularly notable.

- **From Peels**

Peels from fruits and vegetables are often thrown away as agricultural waste, however studies reveal that they have basic ingredients that can be used in pharmaceutical or medicinal applications. Strip extracts have recently been used in the production of green nanoparticles as a decreasing agent. Strip extracts from Citrus sinens, Carica papaya, and Musa paradisiacal were used to create AgNPs, which were tested against various microbial strains. Sengupta et al. (2012) [49] made AgNPs from banana peels, which shown good antibacterial activity against E. Coli, B. subtilis, S. aureus, and Klebsiella sp. in addition to debasing the tone of wastewater.

- **From Bulb, Tuber, Latex, Pod**

Extract from onions (Allium cepa) has as of late been utilized in the biosynthesis of roundabout AgNPs with widths going from 10 to 23 nm as a covering and diminishing agent. As indicated by the scientists, are among the microbes against which the AgNPs effectively hinder growth. During the environmentally friendly production of AgNPs, a variety of chamber/bulb extracts, such as Dioscoreaalata and Crocus haussknechtii Bois, along with Gram-positive and Gram-negative bacterial strains, were employed to evaluate the NPs' bactericidal efficacy [50].

6. CONCLUSION

The investigation of plant-based green biomaterials uncovers how significant a job they play in propelling endeavours connected with reasonability. Through the usage of the innate characteristics of normal assets, these biomaterials give adaptable solutions to various applications, going from biomedical to packaging. A suitable way ahead is the usage of plants as hosts for the expression of biologics, utilizing their versatility, moderateness, and accuracy to increment yields in restorative, contemporary, and country applications. In any case, challenges like proteolytic debasement and downstream handling intricacies require savvy fixes like genetic designing and cleaning strategies, and authoritative contemplations demand cautious examinations. A mix of synthetic biology, metabolic designing, and omics revelations reveals insight into molecular cycles and focuses the way toward when fastidiously designed plant expression systems will assume a significant part in changing cultivation, industry, and medication. This highlights the requirement for coherent interest and extensive information while analyzing this confounding landscape.

REFERENCES

1. *Alfuraydi, A. A., Devanesan, S., Al-Ansari, M., AlSalhi, M. S., &Ranjitsingh, A. J. (2019). Eco-friendly green synthesis of silver nanoparticles from the sesame oil cake and its potential anticancer and antimicrobial activities. Journal of Photochemistry and Photobiology B: Biology, 192, 83–89. https://doi.org/10.1016/J.JPHOTOBIOL.2019.01.011*
2. *Alvarez, M.A. Plants for Health: From Secondary Metabolites to Molecular Farming Chapter 1. In Plant Biotechnology for Health: From Secondary Metabolites to Molecular Farming; Alvarez, M.A., Ed.; Springer International Publishing: Cham, Switzerland, 2014; pp. 1–2. ISBN 978-3-319-05771-2.*
3. *Atanasov, A.G.; Zotchev, S.B.; Dirsch, V.M.; Supuran, C.T. Natural Products in Drug Discovery: Advances and Opportunities. Nat. Rev. Drug Discov. 2021, 20, 200–216.*
4. *Buyel, J.F. Plant Molecular Farming—Integration and Exploitation of Side Streams to Achieve Sustainable Biomanufacturing. Front. Plant Sci. 2019, 9, 1893.*
5. *Buyel, J.F.; Stöger, E.; Bortesi, L. Targeted Genome Editing of Plants and Plant Cells for Biomanufacturing. Transgenic Res. 2021, 30, 401–426.*
6. *Buyel, J.F.; Twyman, R.M.; Fischer, R. Extraction and Downstream Processing of Plant-Derived Recombinant Proteins. Biotechnol. Adv. 2015, 33, 902–913.*
7. *Chan, J.C.N.; Chan, A.T.C. Biologics and Biosimilars: What, Why and How? ESMO Open 2017, 2, e000180.*
8. *Chen, Q.; Lai, H. Plant-Derived Virus-like Particles as Vaccines. Hum. Vaccines Immunother. 2013, 9, 26–49.*
9. *Chen, Q.; Santi, L.; Zhang, C. Plant-Made Biologics. Biomed Res. Int. 2014, 2014, 418064.*
10. *Chung, Y.H.; Church, D.; Koellhoffer, E.C.; Osota, E.; Shukla, S.; Rybicki, E.P.; Pokorski, J.K.; Steinmetz, N.F. Integrating Plant Molecular Farming and Materials Research for Next-Generation Vaccines. Nat. Rev. Mater 2022, 7, 372–388.*
11. *Daniell, H.; Nair, S.K.; Esmaeili, N.; Wakade, G.; Shahid, N.; Ganesan, P.K.; Islam, M.R.; Shepley-McTaggart, A.; Feng, S.; Gary, E.N.; et al. Debulking SARS-CoV-2 in Saliva Using Angiotensin Converting Enzyme 2 in Chewing Gum to Decrease Oral Virus Transmission and Infection. Mol. Ther. 2022, 30, 1966–1978.*
12. *Fischer, R.; Buyel, J.F. Molecular Farming—The Slope of Enlightenment. Biotechnol. Adv. 2020, 40, 107519.*
13. *Gomaa, E. Z. (2017). Antimicrobial, antioxidant and antitumor activities of silver nanoparticles synthesized by Allium cepa extract: A green approach. Journal of Genetic Engineering and Biotechnology, 15(1), 49– 57. https://doi.org/10.1016/J.JGEB.2016.12.002*
14. *Idrees, M., Batool, S., Kalsoom, T., Raina, S., Sharif, H. M. A., & Yasmeen, S. (2018). Biosynthesis of silver nanoparticles using Sida acuta extract for antimicrobial actions and corrosion inhibition potential.*

Https://Doi.Org/10.1080/09593330.2018.1435738, 40(8), 1071–1078. https://doi.org/10.1080/09593330.2018.1435738

15. *Jeeva, K., Thiyagarajan, M., Elangovan, V., Geetha, N., & Venkatachalam, P. (2014). Caesalpinia coriaria leaf extracts mediated biosynthesis of metallic silver nanoparticles and their antibacterial activity against clinically isolated pathogens. Industrial Crops and Products, 52, 714–720. https://doi.org/10.1016/J.INDCROP.2013.11.037*
16. *Khatami, M., Pourseyedi, S., Khatami, M., Hamidi, H., Zaeifi, M., &Soltani, L. (2015). Synthesis of silver nanoparticles using seed exudates of sinapis arvensis as a novel bioresource, and evaluation of their antifungal activity. Bioresources and Bioprocessing, 2(1), 1–7. https://doi.org/10.1186/S40643-015-0043-Y/FIGURES/6*
17. *Mittal, S., & Roy, A. (2021).Fungus and plant-mediated synthesis of metallic nanoparticles and their application in degradation of dyes. Photocatalytic Degradation of Dyes, 287–308. https://doi.org/10.1016/B978-0- 12-823876-9.00009-3*
18. *Moorthy, S. K., Ashok, C. H., Rao, K. V., & Viswanathan, C. (2015). Synthesis and Characterization of Mgo Nanoparticles by Neem Leaves through Green Method.Materials Today: Proceedings, 2(9), 4360–4368. https://doi.org/10.1016/J.MATPR.2015.10.027*
19. *Nandi, S.; Kwong, A.T.; Holtz, B.R.; Erwin, R.L.; Marcel, S.; McDonald, K.A. Techno-Economic Analysis of a Transient Plant-Based Platform for Monoclonal Antibody Production. MABS 2016, 8, 1456–1466.*
20. *Ponarulselvam, S., Panneerselvam, C., Murugan, K., Aarthi, N., Kalimuthu, K., &Thangamani, S. (2012). Synthesis of silver nanoparticles using leaves of Catharanthus roseus Linn. G. Don and their antiplasmodial activities. Asian Pacific Journal of Tropical Biomedicine, 2(7), 574. https://doi.org/10.1016/S2221-1691(12)60100-2*
21. *Ramteke, C., Chakrabarti, T., Sarangi, B. K., & Pandey, R. A. (2013). Synthesis of silver nanoparticles from the aqueous extract of leaves of ocimum sanctum for enhanced antibacterial activity. Journal of Chemistry. https://doi.org/10.1155/2013/278925*
22. *Rybicki, E.P.; Chikwamba, R.; Koch, M.; Rhodes, J.I.; Groenewald, J.-H. Plant-Made Therapeutics: An Emerging Platform in South Africa. Biotechnol. Adv. 2012, 30, 449–459.*
23. *Schillberg, S.; Finnern, R. Plant Molecular Farming for the Production of Valuable Proteins—Critical Evaluation of Achievements and Future Challenges. J. Plant Physiol. 2021, 258–259, 153359.*
24. *SemBioSys. Eligible to Proceed With Phase I/II Plant-Produced Insulin Trial After Submission of IND. Available online: https://www.ots.at/presseaussendung/OTE_20080916_OTE0007/sembiosys-eligible-to-proceed-with-phase-iii-plant-produced-insulin-trial-after-submission-of-ind (accessed on 17 September 2023).*
25. *Shanmugaraj, B.; Bulaon, C.J.I.; Phoolcharoen, W. Plant Molecular Farming: A Viable Platform for Recombinant Biopharmaceutical Production. Plants 2020, 9, E842.*
26. *Sil, B.; Jha, S. Plants: The Future Pharmaceutical Factory. Am. J. Plant Sci. 2014, 5, 319–327.*
27. *Tanvir, R. U., Zhang, J., Canter, T., Chen, D., Lu, J., & Hu, Z. (2021). Harnessing solar energy using phototrophic microorganisms: A sustainable pathway to bioenergy, biomaterials, and environmental solutions. Renewable and Sustainable Energy Reviews, 146, 111181.*
28. *Edrisi, S. A., Tripathi, V., Dubey, P. K., & Abhilash, P. C. (2022). Carbon sequestration and harnessing biomaterials from terrestrial plantations for mitigating climate change impacts. In Biomass, Biofuels, Biochemicals (pp. 299-313). Elsevier.*
29. *Pradhan, S., Brooks, A. K., & Yadavalli, V. K. (2020). Nature-derived materials for the fabrication of functional biodevices. Materials Today Bio, 7, 100065.*
30. *Iravani, S., & Varma, R. S. (2019). Plants and plant-based polymers as scaffolds for tissue engineering. Green Chemistry, 21(18), 4839-4867.*
31. *Karimi-Maleh, H., Atigh, Z. B. Q., Sadeghifar, H., Najafi, M., Rajendran, S., Ayati, A., ... & Kalikeri, S. (2023). Shifting paradigms in PFAS resin removal with biomaterial alternatives. Journal of the Taiwan Institute of Chemical Engineers, 105300.*
32. *Bell, J., Paula, L., Dodd, T., Németh, S., Nanou, C., Mega, V., & Campos, P. (2018). EU ambition to build the world's leading bioeconomy—Uncertain times demand innovative and sustainable solutions. New biotechnology, 40, 25-30.*

33. *Singh, V., Baranwal, K., Dwivedi, L. M., & Shehala, (2018). Guar gum mediated synthesis of NiO nanoparticles: An efficient catalyst for reduction of nitroarenes with sodium borohydride. International Journal of Biological Macromolecules, 120, 2431–2441. https://doi.org/10.1016/J.IJBIOMAC.2018.09.013*
34. *Sumitha, S., Vasanthi, S., Shalini, S., Chinni, S. v., Gopinath, S. C. B., Anbu, P., Bahari, M. B., Harish, R., Kathiresan, S., & Ravichandran, V. (2018). Phyto-Mediated Photo Catalysed Green Synthesis of Silver Nanoparticles Using Durio Zibethinus Seed Extract: Antimicrobial and Cytotoxic Activity and Photocatalytic Applications. Molecules 2018, Vol. 23, Page 3311, 23(12), 3311. https://doi.org/10.3390/MOLECULES23123311*
35. *van der Veen, S.J.; Hollak, C.E.M.; van Kuilenburg, A.B.P.; Langeveld, M. Developments in the Treatment of Fabry Disease. J Inherit. Metab. Dis. 2020, 43, 908–921.*
36. *Ward, B.J.; Séguin, A.; Couillard, J.; Trépanier, S.; Landry, N. Phase III: Randomized Observer-Blind Trial to Evaluate Lot-to-Lot Consistency of a New Plant-Derived Quadrivalent Virus like Particle Influenza Vaccine in Adults 18–49 Years of Age. Vaccine 2021, 39, 1528–1533.*
37. *Wiltschi, B.; Cernava, T.; Dennig, A.; Galindo Casas, M.; Geier, M.; Gruber, S.; Haberbauer, M.; Heidinger, P.; Herrero Acero, E.; Kratzer, R.; et al. Enzymes Revolutionize the Bioproduction of Value-Added Compounds: From Enzyme Discovery to Special Applications. Biotechnol. Adv. 2020, 40, 107520.*
38. *Xu, H., Wang, L., Su, H., Gu, L., Han, T., Meng, F., & Liu, C. (2014). Making Good Use of Food Wastes: Green Synthesis of Highly Stabilized Silver Nanoparticles from Grape Seed Extract and Their Antimicrobial Activity. Food Biophysics 2014 10:1, 10(1), 12–18. https://doi.org/10.1007/S11483-014-9343-6*
39. *Noruzi, M., Zare, D., Khoshnevisan, K., &Davoodi, D. (2011). Rapid green synthesis of gold nanoparticles using Rosa hybrida petal extract at room temperature.Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 79(5), 1461–1465. https://doi.org/10.1016/J.SAA.2011.05.001*
40. *Padalia, H., Moteriya, P., & Chanda, S. (2015). Green synthesis of silver nanoparticles from marigold flower and its synergistic antimicrobial potential. Arabian Journal of Chemistry, 8(5), 732–741. https://doi.org/10.1016/J.ARABJC.2014.11.015*
41. *Zahmanova, G.; Aljabali, A.A.; Takova, K.; Toneva, V.; Tambuwala, M.M.; Andonov, A.P.; Lukov, G.L.; Minkov, I. The Plant Viruses and Molecular Farming: How Beneficial They Might Be for Human and Animal Health? Int. J. Mol. Sci. 2023, 24, 1533.*
42. *Gnanajobitha, G., Paulkumar, K., Vanaja, M., Rajeshkumar, S., Malarkodi, C., Annadurai, G., & Kannan, C. (2013). Fruit-mediated synthesis of silver nanoparticles using Vitis vinifera and evaluation of their antimicrobial efficacy. Journal of Nanostructure in Chemistry 2013 3:1, 3(1), 1–6. https://doi.org/10.1186/2193-8865-3-67*
43. *Kora, A. J., Beedu, S. R., & Jayaraman, A. (2012). Size-controlled green synthesis of silver nanoparticles mediated by gum ghatti (Anogeissus latifolia) and its biological activity.Organic and Medicinal Chemistry Letters, 2(1), 17. https://doi.org/10.1186/2191-2858-2-17*
44. *Alharbi, N. S., Bhakyaraj, K., Gopinath, K., Govindarajan, M., Kumuraguru, S., Mohan, S., Kaleeswarran, P., Kadaikunnan, S., Khaled, J. M., & Benelli, G. (2016). Gum-Mediated Fabrication of Eco-Friendly Gold Nanoparticles Promoting Cell Division and Pollen Germination in Plant Cells. Journal of Cluster Science 2016 28:1, 28(1), 507–517. https://doi.org/10.1007/S10876-016-1130-8*
45. *Baranwal, K., Dwivedi, L. M., Shehala, & Singh, V. (2018). Guar gum mediated synthesis of NiO nanoparticles: An efficient catalyst for reduction of nitroarenes with sodium borohydride. International Journal of Biological Macromolecules, 120, 2431–2441. https://doi.org/10.1016/J.IJBIOMAC.2018.09.013*
46. *Paulkumar, K., Gnanajobitha, G., Vanaja, M., Rajeshkumar, S., Malarkodi, C., Pandian, K., & Annadurai, G. (2014). Piper nigrum leaf and stem assisted green synthesis of silver nanoparticles and evaluation of its antibacterial activity against agricultural plant pathogens. The Scientific World Journal, 2014. https://doi.org/10.1155/2014/829894*
47. *Yugandhar, P., Haribabu, R., & Savithramma, N. (2015). Synthesis, characterization and antimicrobial properties of green-synthesised silver nanoparticles from stem bark extract of Syzygiumalternifolium (Wt.) Walp. 3 Biotech, 5(6), 1031–1039. https://doi.org/10.1007/S13205-015-0307-4/FIGURES/10*

48. *Hettiarachchi, S. S., Dunuweera, S. P., Dunuweera, A. N., & Rajapakse, R. M. G. (2021). Synthesis of Curcumin Nanoparticles from Raw Turmeric Rhizome. ACS Omega, 6(12), 8246–8252. https://doi.org/10.1021/ACSOMEGA.0C06314/SUPPL_FILE/AO0C06314_SI_001.PDF*
49. *Sengupta, A., & Sarkar, A. (2021). Synthesis and characterization of nanoparticles from neem leaves and banana peels: a green prospect for dye degradation in wastewater. Ecotoxicology 2021, 1–12. https://doi.org/10.1007/S10646-021-02414-5*
50. *Zimran, A.; Gonzalez-Rodriguez, D.E.; Abrahamov, A.; Cooper, P.A.; Varughese, S.; Giraldo, P.; Petakov, M.; Tan, E.S.; Chertkoff, R. Long-Term Safety and Efficacy of Taliglucerase Alfa in Pediatric Gaucher Disease Patients Who Were Treatment-Naïve or Previously Treated with Imiglucerase. Blood Cells Mol. Dis. 2018, 68, 163–172.*

****