Application of Biotechnology to Produce Plant-Derived Biologically Important Compounds

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1 Introduction

1.1 Plants as Source of Bioactive Compounds

Secondary metabolites from plants are rich source of bioactive substances that have a variety of health benefits in both humans and animals. Several distinct phytochemicals can be found in plant foods such as vegetables, fruits, grains, seeds, nuts, and legumes. Current findings on phytochemical compounds have suggested that they could be a crucial component of disease-fighting therapeutics and preventatives. These sorts of foodstuffs which include such bioactive constituents are functional foods and, if ingested in a constant and continuous way via meals, would deliver desired beneficial health effects above their natural features. Furthermore, individuals can also get fortified nutritional supplements that provide specific bioactive phytoconstituents or a collection of bioactive components. Such nutritional materials are usually given in higher amounts than it does in a typical diet or even in a medicinal form in order to improve the health of individuals. Polyphenolic compounds, terpenes, alkaloids, and saponins are the four more prevalent classes of bioactive components derived from plants [1]. Based upon the overall optimal activity, biologically active compounds are generally classed as either primary or secondary [2]. Trees and shrubs synthesize hundreds of naturally occurring substances based on physiological phase, tissue distribution (floral and non-floral leaves, fruits, or bark), and ambient circumstances, including natural or anthropogenic stresses. Such molecules might play a role in the cell's fundamental biological mechanisms,

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such as regulating cellular development and growth by serving either plant growth factors, or pheromones [3]. Among those, the much more significant aspects include polyamines, ethylene, gibberellins, brassinosteroids, cytokinins, abscisic acid, and auxin. Nonetheless, their primary purpose is ecologically, particularly in terms of protecting plants from predators, microorganisms, as well as fungus [4]. Plants defend themselves against pathogenic infection via a variety of signal transduction pathways, which are dependent upon physiological and biochemical characteristics (selective or adaptive defences), and proactive modifications generated by infections (active and inducible defence). The benefits of bioactive compounds are picturized in Fig. 1. Substances is also produced at small levels in response to certain circumstances, such as terpenes, while transcription could be stimulated to create excessive proportion in response to structural destruction and pathogenic infection. Transcription factor compounds comprise phytoalexins, pathogen-related (PR) proteins, glucanases, and chitinases, whereas passively and conventional defensive chemicals comprise glucans, terpenoids, antimicrobial activity enzymes, antifeedants, and enzyme inhibitors [5]. Glycosylated and concatenated versions of phytochemicals implicated mostly in defensive response enable the plants to synthesize as well as preserve metabolites in a non-toxic state. For eliminating autoallelopathy and manufacture active forms fast but only when required, polymerization and particular distribution (for example, in extracellular environment or even other intracellular organelles) potential options [6]. Across several plants, however, de novo

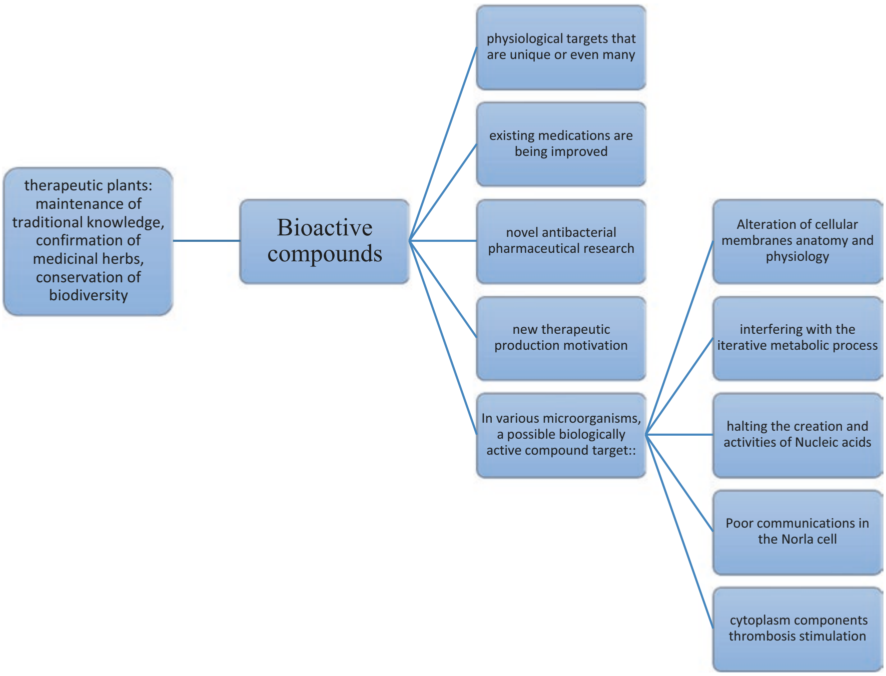

Fig. 1 Benefits of bioactive compounds

production of antifungal agents is indeed reported throughout the course of infection. Phytoalexins were comparable to intrinsic fungicidal poisons; however, they are highly hydrophilic in nature. Plants could also create phytoecdysones, which also have vertebrate physiological function and can affect or trigger early insect metamorphosis. Ultimately, they might play a part in the development of symbiotic relationships involving advantageous fungus and lichens [7]. Several methods are available for extracting biologically active compounds: Traditional methods of extraction include soxhlet, maceration, and water distillation. To limit its use of chemicals as well as provide milder extraction efficiency, researchers have been looking into using sonication, radiation, electrical currents, pressure changes, or supercritical fluid extraction [7]. To get a pure extraction, often known as essential essence, moisture residues could be eliminated (EO). Secondary metabolites are categorized into three types based on their metabolic source: phenolics, terpenes, and nitrogen-containing chemicals. The most important of these bioactive secondary chemicals in terms of antimicrobial and antiaflatoxin activities have been identified [8] (Table 1).

1.2 Commercially Important Plant Metabolites

From antiquity, herbs were used for therapeutic purposes all across the earth. Plants' therapeutic properties are determined by their phytochemical constituents, particularly secondary metabolites, that are excellent sources of high-value phytochemical compounds. Bioactive compounds have complicated chemical characteristics and thus are created in response to internal or external of stresses in order enable plants to execute wide range of physiological activities. They are employed in a variety of sectors, including pharmaceuticals, aesthetics, nutritional supplements, scents, tastes, and colours. The widespread usage of such compounds in a variety of industries has prompted researchers to concentrate their efforts on improving synthesis utilizing plant tissue culture (PTC) technologies and maximizing comparative advantage in the production utilizing culture system [9]. PTC approaches, which are not affected by climate or geographic factors, would allow for continuous, scalable, cost-effective, and practical synthesis of secondary metabolites. The aim of this systematic review is to evaluate the benefits of employing plant cell culture, the dispersion of major bioactive molecules in land plants, various strategies involved in production of secondary metabolites, as well as the industrial value of chosen naturally occurring substances [10]. Herbs always have contributed immensely in both clinical practice and research. Plant-based components are used by about 80% of the worldwide people for essential nutrition and exercise [11, 12]. They are high in phytonutrients, which provide a magical capacity to treat ailments and can be employed in a variety of industries, including medicines, aesthetics, and nutritional supplements. Due to various their cost-effectiveness, convenience, eco-friendliness, and projected effectiveness equivalent to increased conventional pharmacological agents, they are receiving greater attention among some of the increasing

Table 1 List of biologically active metabolites from plants and their uses

Name of plant	Biologically active metabolites	Uses
Datura stramonium	Tropane alkaloids like hyoscyamine scopolamine and atropine	Rheumatoid and arthritis discomfort relief, hallucinating medication, autism and anxiety treatment, potent mind-altering drug, anti-inflammatory, and antibiotic
Species of Rauwolfia	Ajmaline, α-solanine, ajmalicine, solasodine, serpentine and reserpine, β-carboline, reserpiline, alstonine, rescinnamine	Antidote for snake bites, naturally occurring tranquillizer, anxiety, sleeplessness, seizures, and schizophrenic
Ephedra	**Proanthocyanidins** include eucodelphinidin, leucopelargonine, leucoanthocyanidin, lucenine, vicenin-1, and vicenin-2; ephedrine alkaloids include 1-ephedrine, d-pseudoephedrine, norephedrine, norpseudoephedrine, methylephedrine, and methylpseudoephedrine norephedrine, norpseudoephedrine, methylephedrine, and methylpseudoephedrine; and flavonoids include eucodelphinidin, leucopelargonine, leucoanthocyanidin, lucenine, vicenin-1, and vicenin-2	Hunger suppressing, psychostimulants, asthmatic prophylactic, spine anaesthesia-induced nasal congestion and hypotension, and urine discharge
Ginkgo biloba	Ginkgo biloba is a type of plant that grows in the United States. Isorhamnetin, isorhamnetin, quercetin, kaempferol bilobalide, ginsenoside, ginkgolide A, B, C, quercetin, bilobalide, ginkgolide A, B, and C	Anti-inflammatory, antidiabetic, antihypertension, antihypertension, antihypertension, antihypertension, and malignancy
Saussurea medusa	Flavonoids, phytosterols, triterpenoids, lignans, phenolics, gallic acid, syringin, chlorogenic acid, ethyl gallate, rutin, isoquercitrin, gallic acid, syringin, chlorogenic acid, ethyl gallate, rutin, isoquercitrin, and sesquiterpenoids	Anti-inflammatory, antithrombotic, anticancer, immunosuppression, antispasmodic, antibacterial, anticonvulsant, and antioxidative
Thymus species	Rosmarinic acid, borneol, geraniol, carvacrol, thymol, α-terpineol carotenoids	Antibacterial, anti-HIV-1 action, antispasmodic, neuroprotective, antihypertensive, hypocholesterolemic, strong antioxidant ability, and flavor enhancer ingredient
Stevia rebaudiana	Essential oils, stevioside, steviol rebaudioside	Diabetic treatment, coronary heart disease, cancers, kidney disorder, overweight, irritable bowel syndrome treatment, and periodontal disease treatment

(continued)

Table 1 (continued)

Name of plant	Biologically active metabolites	Uses
Maclura pomifera	Isoflavones (scandenone and auriculasin), prenylated isoflavones (osajin and pomiferin)	Cardiac activities, insecticidal, synthetic dye, abrasive, antimicrobial, and fungistatic properties
Citrullus colocynthis	Saponins, steroids, alkaloids, and flavonoids	Diabetic treatment, coronary heart disease, cancers, kidney disorder, overweight, irritable bowel syndrome treatment, and periodontal disease treatment
Bacopa monnieri	Triterpenoid saponins like bacosides	Neural relaxant, memory enhancer, anticonvulsant, gastroprotective, free radical scavenging
Commiphora wightii	Monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, steroids, flavonoids, guggultetrols, and lignans are all found in *Commiphora wightii*	Infection, arthritis, rheumatism, overweight, and lipid metabolic abnormalities can all be treated
Punica granatum	Pelletierine, ellagic acid, phenol, and flavonoid are examples of flavonoid compounds	Anticancer, antiheart illness, antidiabetes, and oral treatment, immune-modulating properties

population [13, 14]. As a result, pharmacodynamics, phytochemical constituents, and agriculture have received the majority of study interest on medicinal herbs to present. The growing demand for these kind of commodities has necessitated the development of ways to increase output without affecting the wild population [10].

The preference of mainstream consumers for natural chemicals over synthesized bioactive molecules contributes toward the utilization of bioactive molecules derived from natural products. Numerous innovative nutritional and pharmacological chemicals come from microalgae. Thus far, almost 15,000 new algae chemicals have been discovered. Carotenoids, fatty acids, enzymes, peptides, toxins, and sterols, for example, are pharmacologically active substances. Astaxanthin, cryptoxanthin, canthaxanthin, lutein, and zeaxanthin are significant algal carotenoids. Numerous factors influence their formation, which includes nutritional supplementation, light, temperature, and pH. Methods have been proposed nonstop to improve algae growing conditions in order to increase the efficiency and competitiveness of these high-value combinations and make them more affordable to consumers.

1.3 Benefits of Using Plant Secondary Metabolites

Plant secondary metabolites (PSM) have been the subject of discussion in the research world due to their supposed antiparasitic characteristics. Despite a long history of indigenous medicinal awareness of the therapeutic and preventive activities of plant secondary metabolites rich preparations, scientific proof of PSM's antiparasitic benefits is inconclusive. Some reasons of this dispute are discussed in the opening section of this study, as well as the evidence presented on antiparasitic properties of plants secondary metabolite. Plant secondary metabolites have antiparasitic effectiveness targeting parasitic worms. Increased plant secondary metabolites use can harm herbivore performance and survivability due to its antinutritional characteristics. As a result, it is recommended that antiparasitic and antinutritional activities of plant secondary metabolites be evaluated simultaneously. While evaluating these features, relatively similar measurement, such as parasitized host effectiveness, should be employed. The cost-benefit analysis indicates that parasitized herbivores can advantage through long-term plant secondary metabolites ingestion unless the antiparasitic advantages surpass the antinutritional factor costs. Furthermore, parasitized animals may gain from plant secondary metabolite ingestion even if their performance is affected, as long as the latter is a positive effect. Bioactive molecules provide protection against oxidative stress, wounds, ultraviolet irradiation, and ozone, as well as allowing plants to respond to constant changes in the external environment. Bioactive compounds are formed mostly from primary metabolites including such amino acids and glucose(carbohydrates) that have undergone addition of methyl group, hydroxylation, glycosylation, or oligomerization [15]. Natural compounds, particularly phenylpropanoids and associated metabolites, appear to be rich source of antioxidants which actively neutralize reactive oxygen species and reactive nitrogen species (ROS/RNS), according to growing data. The maintenance of biological processes requires a delicate balance among oxidative and antioxidative mechanisms. Increased reactive oxygen and nitrogen species generation within organisms production of reactive oxygen species, cell death, and programmed cell death or destruction [16]. Cellular injury is reduced when reactive oxygen and nitrogen species are detoxified through enzymatic or non-enzymatic defenders [17]. The antioxidant potential of 5 phenolics and flavonoids isolated from the persistent plant *Ballota nigra* (i.e., verbascoside, forsythoside, and caffeoyl malic acid) against superoxide, H_2O_2, chlorine oxide, and hydroxide ions produced in cell-free mechanisms was evaluated [18]. Those phenylpropanoids had powerful antioxidant properties comparable to N-acetyl cysteine, a well-known scavenger because of its exceptional impact on human beings including antitumor, free radical scavenging, antiviral, and anti-inflammatory compounds; secondary bioactive molecules are becoming the subject of intense investigation [19]. These chemicals, on the other hand, are mostly extracted from a variety of plant lysates and cultured cells of plant at a high costs and productivity. Pharmacologically manufacturing these compounds is both costly and difficult. As a result, new, accurate, and cost-effective strategies for order to enhance the efficiency of biologically active secondary metabolites are urgently needed [20]. Cyanobacteria have a number of characteristics that contribute to making them palatable representatives for the biosynthetic pathways of secondary metabolites in plants, including photosynthetic capacity, genetically engineered potential, as well as the ability to thrive in extreme conditions. The capability of soil to promote the survival of animals and plants behind and in front of earth, as well as ecological integrity, encompassing water and air, is described as soil health. Mechanical, biochemical, and biological factors of soil are all interconnected. The physical and chemical properties as well as the soil microbiology are influenced by physical hierarchy, which in turn determines metabolic processes. Chemical qualities comprise cation-exchange capability, pH, saltiness, vitamins and nutrients, as well as morphology, smoothness, permeability, and bulk density. Plant biodiversity is lost as a result of agricultural practices that impair plant physiochemical complexity and ground biodiversity [21]. The benefits of secondary metabolites to plants were explained in Fig. 2.

1.4 Strategies for Improving Production or Secondary Metabolites

Transgenesis (additionally called genetic transformation or genetic engineering) is the most current step to increase genetic variability available in the crop. Transgenesis targets to introduce, via special strategies, a particular gene (covered in a gene construct) from a donor species into the genome of a host species. Organisms as a consequence of transgenesis are usually referred to as genetically modified organisms (GMOs). Transgenesis is getting used to introducing an extensive variety of the latest agronomic, processing, and dietary developments into the main agricultural and vegetable crops. In contrast to embryo rescue and protoplast fusion, transgenesis is not restricted through reproduction limitations. Genes can be transferred from one realm into some other. Furthermore, only the particular gene construct is introduced within the host organism. This offers excellent precision and rapidity to the enhancement method. Transgenesis is a totally promising device for the development of recent types with precise traits that are not present in the crop gene pool [22].

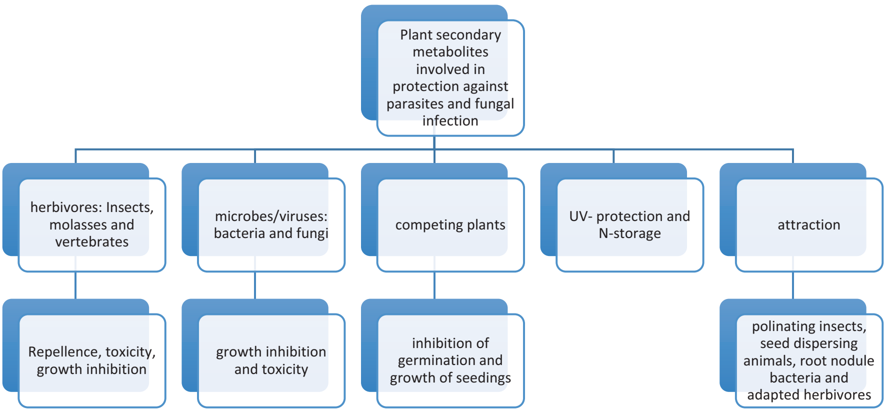

Fig. 2 Benefits of using plants secondary metabolites

Numerous genome-editing tools including transcription activator-like effector nucleases (TALENs), zinc-finger nucleases (ZFNs), and meganucleases (MNs) have enabled plant scientists to control favored genes in crop vegetation. But these strategies are costly and exhausting related to complicated techniques for successful editing. Conversely, CRISPR/Cas9 is an entrancing, easy-to-design, fee-powerful, and flexible tool for specific and efficient plant genome editing. In recent years, the CRISPR/Cas9 system has emerged as an effective tool for targeted mutagenesis, which includes single base substitution, multiplex gene editing, gene knockouts, and regulation of gene transcription in plants. As a consequence, CRISPR/Cas9-primarily based genome editing has validated outstanding capacity for crop improvement; however, regulation of genome-edited plants remains in its infancy. Here, we considerably reviewed the supply of CRISPR/Cas9 genome-enhancing tools for plant biotechnologists to target favored genes and its great applications in crop breeding research. There are three kinds of modifications produced through genome editing: type I involves altering some nucleotides, type II includes substitute an allele with a pre-existing one, and type III permits for the insertion of latest gene(s) in predetermined regions in the genome. Due to the fact maximum genome-modifying strategies can leave behind traces of DNA alterations obvious in a small quantity of nucleotides, crops created by gene editing could avoid the stringent regulation strategies generally related to GM crop improvement. For that reason, many scientists consider plants improved with more specific gene editing strategies could be more desirable to the public than transgenic plants. With genome editing come the promise of recent plants being developed more rapidly with a very low risk of off-target outcomes. It may be done in any laboratory with any crop, even people who have complicated genomes and are not easily bred the use of traditional techniques [23]. The various techniques and its applications are discussed in Table 2.

Classical Biotechnology and Current Next-Generation Sequencing (NGS) techniques were correctly used to optimize plant-derived herbal products of biomedical importance. In advance, protein primarily based enhancing tools, viz. zinc-finger nucleases (ZFNs) and transcription activator-like endonucleases (TALENs) have been popularized for transcriptional level genome manipulation. Clustered often interspaced short palindromic repeats (CRISPR)/CRISPR-associated 9 (Cas9) endonuclease device is an effective, strong, and selective site-directed mutagenesis method for RNA-guided genome-modifying. CRISPR/Cas9 genome-editing tool employs designed guide-RNAs that identifies a three base-pair protospacer adjacent motif (PAM) sequence occurring downstream of the target-DNA. The existing review comprehensively complies the latest literature (2010–2020) retrieved from scientific databases on the application of CRISPR/Cas9-enhancing tools as effective genome-editing techniques in medicinal plants discussing the latest developments, challenges, and future perspectives with notes on broader applicability of the technique in plants and lower organisms. In plants, CRISPR/Cas editing has been applied effectively in terms of crop yield and stress tolerance. But very few medicinal plants were edited the use of CRISPR/Cas genome device due to the shortage of entire genome and mRNA sequences and shortfall of appropriate transformation and regeneration techniques. However, currently some of plant secondary metabolic

Table 2 Different techniques and its applications

Different techniques	Applications
Cluttered tissues	Tissue clonal variability, mass production of plants in the lab, regeneration of seedlings during planting
Nucleic acid isolation and purification	Biotech, diagnostics, and molecular genetics
DNA and RNA electrophoresis	Determination of DNA and RNA size, recovery and purifying of nucleotide sequences, study of PCR results in molecular diagnosis, and fingerprinting
The use of markers (marker technology)	Hereditary of plants and animals
Protein purification and isolation	Commercialized items including enzymes, dietary proteins, and biopharmaceuticals are prepared using this method
PCR-based gene amplification	Diagnostics, criminology, and contagious disorders all benefit from gene amplification by PCR
Technology based on enzymes	Food, drinks, fabrics, and cleansers are all products that use enzyme technology
Protein electrophoresis	Protein extraction and characterization by electrophoresis
Micropropagation	Enables the generation of disease-free plants and the regeneration of genetically manipulated cells
Genomic fingerprinting	Criminology, medical diagnoses, maternity determination, and archaeology all use genomic fingerprinting
Recombinant DNA	Pharmaceuticals, biological and biomedical screening facilities, agricultural biotech all use recombinant DNA

pathways (viz. alkaloid, terpenoid, flavonoids, phenolic, saponin, etc.) had been engineered using CRISPR/Cas editing through knock-out, knock-in, point mutation, fine-tuning of gene expression, and targeted mutagenesis. This genome-enhancing tool similarly extends its applicability by incorporating the tools of artificial and systems biology, useful genomics, and NGS to produce genetically engineered medicinal plants with advanced trends facilitating the production of pharmaceuticals and nutraceuticals [24].

To resolve discrepancies in species identification and taxonomy, DNA-based technologies such as PCR, RFLP, AFLP, RAPD, and genotyping may be used. Biologically active compounds (alkaloids, flavonoids, terpenoids, etc.) can be produced in vitro using plant organ and tissue culture procedures under controlled conditions. Recombinant DNA techniques can be utilized to manipulate metabolic pathways and create protein medicines such as antibodies and hormones. Bioinformatics and genomics, two new sciences, can be used to identify new drugs using plant-based materials. Biotechnological strategies, we conclude, can improve and strengthen medicinal plant research.

1.5 Approaches for Producing Bioactive Chemicals via Genetic Engineering

Agricultural biotechnology continues to generate advantageous goods or services, such as unique bioactive phytochemical compounds, flavones, and polyphenolic, saponins, terpenoids, steroids, glycosides, tannins, volatile oils, and several others, from plant cells, tissue samples, or organs cultured unbiased of environmental and geographical factors under aseptic conditions. Medicines (pharmaceuticals), flavors, fragrances (perfumes), pigments (dyes), herbicides and pesticides, aesthetics, dietary supplements, and other bioactive molecules are all economically significant [25].

For the generation of bioactive metabolites of secondary metabolic origin, many approaches such as genetic alteration of plant life using A. tumefaciens rhizogenic, hairy roots, and others may be used. Strategies based on recombinant DNA can be employed to enhance metabolic processes and create protein medicines such as immunoglobulin and hormones [26]. Bioinformatics and genetics can be used to discover new drugs from plant-based compounds, and biotechnological methodologies can help to improve and expand indigenous medicinal research. Genetic biotechnology studies and modifies nucleic acids and proteins in the lab for implications in humans and livestock, farming, and the ecosystem [27].

1.6 Biotechnology and Bioactive Compound Production, as Well as Molecular Biotechnology Techniques

Alkaloids, flavonoids, and other phenolic compounds, saponins, terpenoids, steroids, glycosides, tannins, unstable oils, and other bioactive secondary metabolites are all produced by plants. Tablets (prescribed medications), flavors, perfumes (fragrances), pigments (dyes), agrochemicals as well as cosmetics, food components, and other uses for secondary bioactive compounds are among the most common. Because in vitro production of these substances at a commercial level is challenging due to sophisticated chemical compositions and complicated biochemical processes, the majority of those metabolites are acquired from plant life. Biotechnology provides a valuable tool for supplying required quantities of chemicals in an environmentally responsible manner [28]. Callus, suspension, immobilized cells, and differentiation cultures are the four most essential procedures used in this method. Callus culture is the process of cultivating a disorderly mixture of cell from plant plantlets on a semi-solid substrate that includes essential minerals and any hormones needed to stimulate cell growth. When a callus is immersed in liquid nutrient medium and developing cells as a dispersed cell subculture, suspension cultures are formed. Suspension cultures are widely used in the research of pharmacological bioactive compound synthesis by plant cells because of their rapid development.

Bioactive compounds have biotechnological importance because numerous of them are economically valuable synthetic chemicals, certain of them seem to be harmful and must be removed from food, and they act as plant defenders against insects, diseases, and foragers. The following is a summary of the various goals achieved/achievable through the use of plant biotechnology: (1) synthesis of advantageous biochemicals (massive-scale cell cultures), (2) through use of biomarkers and genomic maps to aid traditional breeding efforts, (3) rapid clonal multiplication (haphazard shoot/bulb/protocorm), (4) generation of haploids to develop homozygous lines quickly (anther culture, ovary culture, interspecific hybridization), (5) hybrid manufacturing that is hard to procure (embryo rescue, pollination), (6) removal of the virus (thermotherapy, cryotherapy, or chemotherapy coupled with meristem culture), (7) plants that reproduce vegetative propagation or that produce refractory seeds must have their germplasm conserved (cryopreservation and DNA clones), and (8) vegetational genetic modification (soma clonal variant, somatic hybridization, and gene transfer).

Advantages of Tissue Cultures in Production of Useful Bioactive Compounds
In vitro propagation has become a dependable approach for mass synthesis of plant material as the demand for innovative goods generated from plant life has risen. These and a number of additional advantages of using plant cell culture for huge quantity of critical bioactive chemicals at the industrial stage provide encouragement for its application. The following are a few of the advantages:

(a) Plant-cultured cells are unaffected by environmental factors.
(b) Cellular cultures gain by synthesizing bioactive secondary metabolites and going on walks in a controlled setting, regardless of climate or soil conditions.
(c) Production phases can be more geared, as they should be in accordance with market demand.
(d) By utilizing defined cell strains, a higher level of product production and yield could be preserved.
(e) Because our understanding of the biosynthesis pathways of popular phytochemicals in plants and cultures is frequently still in its infancy, solutions that are primarily centred on a cellular and microscopic level were required.
(f) These findings suggest that plant cellular cultures in vitro have the capacity to produce secondary metabolites in industrial quantities.
(g) Cellular lifestyles will reduce strain on already overharvesting pharmaceutical and other commercially important plant life. Use of in vitro propagation for the synthesis of organic compounds and prescription medications has made huge leaps forward in plant research.
(h) The increased use of herbal products for medical purposes, along with low product yields and plant harvest supply concerns, has reignited interest in large-scale plant cellular culture technologies.
(i) The development of more modern molecular biology technologies for producing transgenic cultures and controlling the translation and regulation of biosynthesis pathway is also likely to be a key step toward creating biological cultures more widely applicable for secondary metabolite production.
(j) From mutant cellular lines, new synthesis methods may be discovered, potentially leading to the development of novel products [28].

1.7 Current and Future Perspectives

Despite more focused efforts and intelligent techniques to enhance value to the country's herbal sector, the preferred production has not yet reached its maximum potential. Despite this, the key challenging scenarios such as a lack of great research documentation, monographs, uniformity in farming practices (excellent agricultural practices, gap), good laboratory practice (GLP), and product enhancement and commercialization persist. Furthermore, increased medicinal herb harvesting raises concerns about plant extinction and deterioration of medicinal herb habitat, resulting in a shortage of plant raw materials, which could stymie efforts to achieve excessive mass manufacture of secondary metabolites. Biotechnological programmes, in combination with plant tissue cultures, have been identified as an alternate technique for scaling up secondary metabolite synthesis [29]. This includes knowledge of naturally occurring substances and their biochemical functions, selection of the highest-yielding populations, specific genomic expression and regulating enzyme management, and the use of cost-effective sterile bioreactors. A continuous effort from the government, academia, and business to further nourish and sustain the herbal sector is critical, leveraging the country's wealth of plant species. Certainly, the characteristics and dynamics of PSM-purposeful microbiome interactions in maximum economic crops are still unknown. A few economically important plants, such as ginger and garlic, can be used as models to study such interactions and improve the synthesis of the ideal metabolites allicin and curcumin for commercial purposes. Certainly, understanding the connection between economic crop PSMs and useful microbiome can lead to stepped-forward agricultural practices that enhance plant fitness and increase the yield of useful secondary metabolites [30, 31].

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