Recent Advancement Toward the Application of Proteomics, Metabolomics, Genomics and Bioinformatics for the Improvement of Nanofertilizer Research

Oluwafemi Adebayo Oyewole[1], Clement Shina Olusanya[1*], Japhet Gaius Yakubu[1], Oluwadurotimi Samuel Aworunse[2], Ezugwu, Basil Utazi[1], Charles Oluwaseun Adetunji[3], Eniola K. I. T.[4] and Mohammed Bello Yerima[5]

[1]*Department of Microbiology, Federal University of Technology, Minna, Nigeria*
[2]*Department of Biological Sciences, Covenant University, Ota, Nigeria*
[3]*Department of Microbiology, Edo State University, Uzairue, Nigeria*
[4]*Department of Biological Sciences, Joseph Ayo Babalola University, Ikeji Arakeji, Osun State, Nigeria*
[5]*Department of Microbiology, Sokoto State University, Sokoto, Sokoto State, Nigeria*

Abstract

The usage of chemical fertilizers is upsetting the ecology in addition to harming human health. Biofertilizers promote plant development by boosting the delivery of nutrients or compounds that promote plant growth. Growing in popularity in the agriculture sector of developing nations is a novel strategy called nanotechnology. Plants exposed to adverse environments respond to nanoparticle stimuli by activating a variety of defense mechanisms. Biofertilizer and nanotechnology were combined to create nanobiofertilizer, which increased agricultural output and efficiency. These fertilizers offer a number of benefits over conventional fertilization techniques and can be utilized to increase agricultural output while minimizing the harmful impacts of fertilizer on the environment. The maintenance of soil moisture and plant uptake of vital nutrients are made easier by the synergistic action of nanomaterial and microbial fertilizer. Additionally, bionanofertilizers are a low-cost solution to boost soil health, plant nutrient uptake, and growth

**Corresponding author*: clementshina1@gmail.com

Charles Oluwaseun Adetunji, Chukwuebuka Egbuna, Anton Ficai and Oluwatosin Ademola Ijabadeniyi (eds.) Handbook of Agricultural Biotechnology: Volume V Nanobiofertilizers, (463–490) © 2024 Scrivener Publishing LLC

and production. A new area of research into the production of inorganic and organic bionanoparticles as environmental fertilizers has been launched through the use of bacteria, algae, yeast, fungi, actinomycetes, and plants to biosynthesize nanomaterials. The microbes used as biological fertilizers include *Azotobacter, Pseudomonas* sp, *Bacillus* sp, and *Enterobacter* sp. In order for these nanobiofertilizers to be produced commercially and made available to farmers, it is necessary to research and develop more suitable ones. Nanobiofertilizer is still not widely available for purchase. And the application of proteomics, metabolomics and genomics and bioinformatics in nanobiofertilizer research can provide a comprehensive understanding of the molecular mechanism underlying plant microbe interaction, nutrient delivery, and crop growth promotion. This knowledge can be exploited to optimize the composition and functionality of nanobiofertilizers, resulting in nutrient use efficiency, improved crop productivity, and environmental sustainability.

Keywords: Agriculture, plant, bionanoparticles, nanobiofertilizer, proteomics, metabolomics, genomics, bioinformatics

18.1 Nanobiofertilizer

Agriculture is regarded as the foundation of many developing and industrialized nations and plays a significant role in the global economy. There are numerous health risks and environmental issues associated with the continual and widespread use of chemical fertilizers in agricultural systems to boost yields. To increase agricultural output and environmental sustainability, a new system must be developed. It appears to be feasible to implement and advance developments in nanotechnology, which has led to the use of nanomaterials with living organisms, such as nanobiofertilizers [1]. A novel strategy that is gaining popularity in the agriculture sector of developing nations is nanotechnology. When plants are subjected to unfavorable conditions, nanoparticles act as cues to activate a variety of defense mechanisms. Comparing nanoparticles to ordinary salts, they are a better source of fertilizer because of their large surface area, high solubility, and lightweight nature [2]. For improved agricultural yield and efficiency, nanobiofertilizer combines nanotechnology and biofertilizer. The cooperative action of nanomaterial and microbial fertilizer allows for the preservation of soil moisture and plant uptake of vital nutrients [3]. Farmers can profit greatly from using nanobiofertilizer because it performs well in the field, is inexpensive, reduces expenses, and increases production. Poor growth and poorer yields may come from other fertilizers' significant limitations, which include their short-term effectiveness and requirement for a lot of fertilizer to cover a vast area, as well as their instability on the field due to changes in temperature, pH, and environmental conditions [4]. Nanobiofertilizers use essential nutrients like potassium, nitrogen, and phosphorus to boost the efficiency of the local bacteria population in addition to being environmentally benign. The greatest grade crops are produced as a result. Additionally, this will boost microbial enzyme activity, which enhances soil fertility [3].

Nanobiofertilizers, also known as biosynthesized nanofertilizers, are the most modern and high-tech way to supply crops with the mineral nutrients they need to grow. The ability of a biological process to precisely control the particle's form would be very advantageous. The benefit of obtaining microorganisms in bulk in a comparatively pure state—devoid of other cellular proteins connected to the organism with relatively simpler downstream processing—comes from their extracellular release. It seems promising to use particular enzymes released by fungi in the creation of nanoparticles [3].

18.1.1 Obstacles to Traditional Agriculture's Widespread Use of Fertilizer

Conventional farming is the practice of cultivating crops in a monoculture using continual interventions such as synthetic chemical fertilizers, fungicides, herbicides, and other pesticides. Traditional agriculture requires a lot of fertilizer because of the aforementioned reasons in order to produce the desired amount of food. Improved fertilizer use, however, does not ensure improved crop production. Despite the fact that this method of agricultural production can supply the current demand for food, the foundation of their products is under jeopardy. The massive mismatch between the supply and removal of plant nutrients has a negative impact on nature in addition to imposing a high financial burden on the neighborhood and the farmer. For example, important macronutrients like K, P, and N that are provided to the soil are lost by 52–95%, 82 -92%, and 45–75%, respectively, resulting in a severe dearth of resources. According to the aforementioned data, conventional fertilizers' high nutrient release rates hinder the efficiency of nutrient uptake.

The three main nutrients nitrogen, phosphorous, and potassium (NPK) are artificially created in the right amounts and combinations for a variety of crops and growing circumstances. On the other hand, these elements become immobile in the soil due to edaphic processes, which prevents plants from absorbing them quickly and enough [5]. Experts estimate that only 30% of applied fertilizers are utilized by plants; the remainder is lost as a result of mineralization, leaching, and bioconversion, significant environmental problems will result from this, including eutrophication of the water supply and groundwater pollution. The process of eutrophication, which is brought on by an increase in the nutrients available to surface water, especially nitrogen and phosphorus, increases the production of important builders, including phytoplankton and aquatic plants. This can cause a variety of problems, including decreased water quality, the appearance of unpleasant odors, the creation of oxygen shortages in water bodies' most remote areas, the production of dangerous NH_3, modifications to the distribution of marine animals, the expansion and contraction of fish populations, and alteration to the reproductive conditions of marine fish flora. Additionally, the 'nitrate,' or dissolved form of nitrogen, in nitrogenous fertilizers has an impact on water supplies, notably groundwater, through draining, leaching, raising worries about groundwater pollution. The most prevalent phosphate, nitrate, ammonium, and potassium salts are found in non-organic fertilizers. Thanks to the use of inexpensive fertilizers and high-yielding crop varieties, farmers may perform mono-cropping, or cultivating the same crop year after year on the same field, without considerably depleting the nitrogen content of the soil or dealing with significant pest issues. Farmers then began focusing their efforts on monoculture, which results in severe soil erosion due to the salinity of the ground and lowers soil fertility when fertilizer is used on a regular basis, which opens the door to further crop failure going forward. Additionally, the fertilizers contain radionuclides such as 238U, 232Th, and 210Po, as well as heavy metals like Cu, Hg, Pb, Cd, and Ni. This means that applying more fertilizer than is required could be harmful to ecosystem and the buildup of heavy metals in plant and soil system [6].

18.2 Constituents of Nanobiofertilizer

Nanobiofertilizer constitutes are mainly biofertilizer and nanoparticles.

18.2.1 Biofertilizer

Biofertilizers, which are biologically active formulations with beneficial live microorganisms in cost-effective transfer materials, are apply to the plant, soil, or seeds to increase plant growth and development by boosting the delivery of nutrients or chemicals that stimulate plant growth [7]. The three primary types of microbes used to generate inoculants are nitrogen-fixing rhizobia, plant-growth-promoting rhizobacteria, and arbuscular mycorrhizal (AM) fungi. The genera *Gigaspora, Glomus, Bacillus, Pseudomonas, Azotobacter, Azospirillum, Bradyrhizobium*, and *Rhizobium* are widely used for the production of inoculants [8]. These bacteria are crucial to the soil ecosystem's ability to maintain and replenish its nutritional richness. Numerous researches have examined the benefits of biofertilizers in sustainable agriculture, notably in terms of improving plant nutrition [9]. Phytohormone synthesis, nutrient mobilization and solubilization, nitrogen fixation, diverse microbial communities, and improved soil physicochemical qualities are a few of these benefits [7].

18.2.1.1 Biofertilizer Production

The biofertilizer production is less expensive and challenging than that of chemical fertilizer. However, when creating biofertilizer, important factors including microbial strains, combination type, transfer/carrier materials, and field usage are considered. In essence, before standardizing the commercial manufacturing process of biofertilizers, six basic phases must be taken into account [7].

In the first stage, microorganisms that have the potential to be active, non-toxic, and able to support plant growth are isolated, identified, and functionally described. Frequently, microbial strains are isolated from bulk soil, the rhizosphere, or plant tissues like leaves, stems, roots, seeds, and flowers. Standard laboratory techniques, such as qualitative testing or different types of growth media, are used to characterize the microbial strains' functions. Because functional features can be evaluated more quickly and inexpensively than strain-specific assessments, they are employed as a generic inoculants' quality control factor. The choice of a pure isolate of the strains targeted is made in the second stage based on the desired field effects of biofertilizers, such as mobilization and solubilization of nutrient, nitrogen fixation, phyto-hormone synthesis, or a combination of these effects. Through additional *in vitro* testing, such as growth on particular media and quantitative measurements of potency, the appropriateness of chosen strains is further examined. Prior to being deployed in the field, the strains are also tested in a greenhouse experiment as part of the selection step to determine their efficacy. This step also examines the mechanisms and pathways through which the strains promote plant growth. A comparative analysis of culture-based methodologies and molecular tools, including as genomics, metabolomics, proteomics, and transcriptomics, have made it possible to compare the ability of inoculant strains to promote plant development. The second step entails choosing a pure isolate of the target strains based on the beneficial properties of field biofertilizer, such as such information can be used to create biofertilizer that will work best in a variety of agricultural settings. For instance, since molybdenum is required for N-fixation, it might be included in the N-fixing inoculants and applied to soils with low molybdenum levels [7].

Choosing appropriate formulation ingredients in the third step, which determines whether the final product will be liquid or carrier-based (such as granular, powder, or slurry), is essential. For the microbes to remain alive and in the proper quantity, the carrier is crucial. The fourth step is choosing a practical propagation strategy for the development and multiplication of the selected strains in the laboratory under ideal conditions, in order to preserve the inherent properties of the microbial strains for effective performance when used in the field. Realizing the appropriate settings requires monitoring the microbial growth profile in diverse environments. The growth of strains is frequently facilitated by the use of a conventional fermenter system. Solid-state fermentation and submerged fermentation are the two primary types of fermentation used in the manufacturing of biofertilizers. The fifth step, prototyping, involves evaluating alternative product configurations. This stage ensures that the best product type is selected for the job at hand. Prior to creating an official standard operating procedure for commercial production, step six involves extensive field testing of the products to ascertain their true effectiveness and limitations in a variety of ecological regions and conditions [7].

Any product must be correctly made and applied in order to have the desired effect on the crop. Effective microbial inoculants must be identified in the current environment so that they can be utilized as an inoculant for a variety of soil conditions. Biofertilizer formulations can be either solid-based or liquid, and the former can be either dry or wet depending on the situation [7].

18.2.1.1.1 Liquid Formulation

The polymers are added to the microbial cultures to enhance stability, adhesion, and dispersion capability. The liquid inoculants are combinations or mixtures of microorganism with other liquids like water, polymers, and oil. Liquid inoculants now rule the market because they are less expensive and simpler to create than solid formulations. To increase the vitality of the microbial culture during storage, several protective chemicals are added to the liquid medium after the bacterial cultures have been harvested or prepared. These include glycerol, horticultural oil, monosaccharides, natural polymers, and synthetic polymers. Overly simple and inexpensive formulation. The added polymers, according to reports, create a microenvironment with an increased water activity, which lowers heat transmission and maintains conditions that are conducive for bacterial survival. However, nutritional deficiency and heat shock, which reduce the population of viable cells, are the fundamental reasons why microorganisms are susceptible to abiotic stresses. During cold storage and application, a formulation's viable cell count must be at least 107 cfu/ml [10].

In order to create biofertilizer in the forms of granule and powder, previous studies used strains of *Pseudomonas azotoformans* C2-114 and *Bacillus licheniformis* BDS31 plant growth-promoting bacterium (PGPR). A 1010 cfu/ml bacterial solution was immobilized on a variety of substrates, including sodium alginate, starch, and the binder polyvinylpyrolidone. The mannitol-supplemented granule biofertilizer (Granule + M3: 59% mannitol, 10% PVP, 6% sodium alginate, 10% starch, 5% bacterial cells, and 10% water) was found to have the highest rate of bacterial cell survival. By using biofertilizer, *Dipterocarpus alatus* seedling development was improved, and after 30 days after seedling cultivation, Additionally, it increased plant height and leaf count. This efficiency was on par with that of chemical and commercial biofertilizers [10].

18.2.1.1.2 Solid Formulation

Solid formulations include organic or inorganic carrier molecules as well as granulated or powdered microbiological culture preparations. Based on particle size and intended use, solid bioinoculant formulations can be divided into two categories. The composition of solid formulations containing carriers, additives, and protectants is generally the same whether they are wet or dry. In contrast, there is no drying process in a wet formulation, therefore the water content is high both during storage and application. The wet formulation also includes charcoal, peat, clay, and biogas sludge blended with enriched soil, it is alginate-based, and also the criteria for choosing a carrier should include price, chemical stability, toxicity, and suitability for farmer management [10].

In a solid wet-formulation, PGPR immobilization works by either forming a biofilm, adhering to a support, or can also be curbing over alginate beads to protect from the effects of severe environments. *Azospirillum brasilense* Ab-V5 was trapped on biodegradable foam by *Azospirillum brasilense* Ab-V5 biofilm production, and the foam was generated using ordinary compounds and by-products from various industries, such as sugarcane bagasse, glycerol, and cassava starch. *Pseudomonas putida* A (ATCC 12,633) was trapped by Liffourrena and Lucchesi [11] over alginate

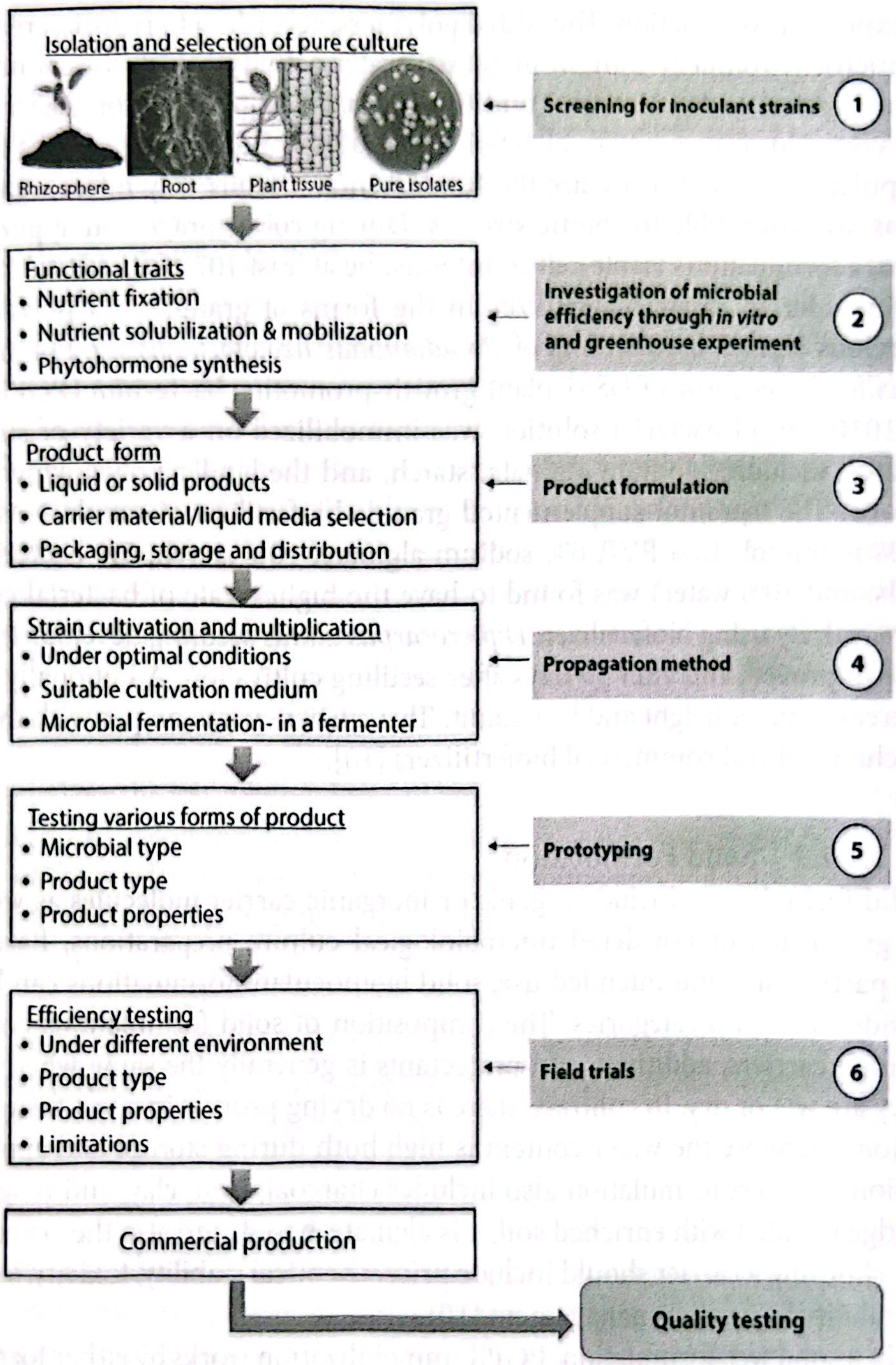

Figure 18.1 Production of commercial biofertilizers [7].

beads that also included highly resistant inorganic perlite. Additionally, it gave the beads mechanical stability and improved bacterial survivability. The electrospinning-based nano-immobilization of microbial bioinoculants is another recent method. Dry formulations lack a substantial water content, extending their shelf life [11]. Figure 18.1 shows the production

Table 18.1 List of some plant growth-promoting bacteria as biofertilizers and their function.

S/N	PGPR	Benefits of PGPR	Plant	Reference
1.	*Azotobacter chroococcum*	Production of ammonia and HCN, IAA synthesis, P solubilization	*Curcuma longa*	[13]
2.	*Pseudomonas stutzeri*	N2 fixation, siderophore production, and IAA	*Capparis spinosa*	[14]
3.	*Bacillus subtilis*	P solubilization, GA production	Alder	[12]
4.	*Enterobacter asburiae*	HCN, ammonia production, P solubilization	Maize	[15]
5.	*Pseudomonas polymyxa*	Controls of fungal disease	Sesame	[12]
6.	*Streptomyces marcescens*	Controls blue mold disease	Tobacco	[12]
7.	*Pseudomonas fluorescens*	Cytokinin production	Soybean, rape	[12]
8.	*Glomus mosseae*	Enhance seed germination and leg hemoglobin content	Vigna mungo	[16]

of commercial biofertilizers and Table 18.1 shows the list of some plant growth-promoting bacteria s biofertilizers and their function.

18.2.1.2 Mode of Microorganism as Biofertilizer

It has been proven that the interaction of helpful microorganisms and plants boosts crop yields safely and is a good replacement for synthetic fertilizers by improving agricultural production. There are various types of helpful microbes from bacteria, algae, fungi, and protozoans that are utilized as biofertilizers to increase agriculture's production and sustainability. Beneficial microorganisms either directly or indirectly promote plant growth [12].

Direct techniques are nitrogen fixation, potassium, phosphorus, and zinc solubilization, siderophore synthesis, phytohormone synthesis, enzyme synthesis, and vitamin synthesis. These effects prompt physiological and morphological changes in plants, fostering plant growth. While the indirect action refers to biofertilizers' ability to lessen phytopathogens' negative impacts on crop development and productivity. A few examples of indirect approaches include production of antibiotics, and the production of hydrogen cyanide, the induction of systemic resistance, and the use of enzymes that break down cell walls [12].

18.2.1.3 Recent Advancement in Biofertilizer

The best technologies, appropriate carrier materials, and the application of specific microorganisms for plant inoculation are examples of recent advancements that have improved soil nutrients and plant growth dynamics for the benefit of agricultural production. Additionally, recent methods include artificial microbiome selection, mixed inoculants, PGPR as biofertilizers, usage of biofilm as biofertilizers, nanobiofertilizers, and bio-organo-chemical fertilizers to lower the cost of biofertilizer and to promote sustainable production [17].

18.2.2 Nanoparticles

In forestry and agriculture, nanotechnology offers the potential to address a number of issues. It is widely acknowledged that nanoparticles (NPs) have at least two dimensions and range in size from 1 to 100 nm. Green manufacturing strategies utilize biological sources instead of the numerous hazardous chemicals and severe conditions required for the physicochemical production of these nanoparticles [18].

Plant roots are exposed to nanoparticles that have been administered to the rhizosphere by endocytosis, carrier proteins, or plasmodesmata. They enter the vascular bundles and pass through the stomata when used as a foliar spray. They also navigate the plant utilizing the apoplastic and symplastic pathways. The migration path of the particles is determined by the type of plant and the type of nanoparticle [18].

18.2.2.1 Nanoparticle Use in the Synthesis of Nanobiofertilizer

18.2.2.1.1 Silicon Nanoparticle

The abundant amount of silicon in soil is regarded as a chemical that is good for plants. It exists as monosilicic acid, with the chemical formular $Si(OH)_4$. The intensive usage of agricultural areas reduces the soil's silicon content and results in plants lacking in silicon. An estimated 200 to 220 million tons of silicon are taken out of the fields annually. Silicon promotes metabolic synthesis and plant development. Under stressful circumstances, plants develop tolerance or resistance. Plants have silica transporters that move silica in the opposite direction of the concentration gradient. Different factors affect how silicon is absorbed and translocated in plants. Additionally, it depends on the species of plants. While few plants are silicon accumulators, some are not. In comparison to non-accumulators, which have an Si concentration of less than 1%, silicon accumulators ingest about 1% of the plant's dry biomass [2]. The element silicon is regarded as being almost necessary. It positively regulates gene expression, which confers stress tolerance on the plant. It decreases the damaging effects of oxidative stress on plant and also increased the uptake and transfer of nutrients from roots up to the aerial parts of plants. It is known that plants that get silicon treatment exhibit a decrease in transpiration rate and an increase in photosynthesis rate. Additionally, it lessens the negative impacts of diseases and insects [19].

18.2.2.1.2 Zinc Nanoparticle

Many enzymes in plants contain zinc (Zn), which is a crucial component. It is a micronutrient that stimulates certain carbohydrate metabolism-related enzymes. It contributes significantly to DNA transcription and functions as an enzyme co-factor. It is essential for the biochemical metabolism of auxin, protein, glucose, starch and processes of photosynthesis. It's responsible for the maintenance of the structure and functionality of biological membranes. The amount of potassium in the cells as well as the timing of stomata's opening and closing are also controlled by it. Zn deficiency prevents tillering, results in chlorosis, and stunts crop growth. It slows down pollen production, has an impact on pollen tube development, and lessens the rate of fertilization and seed germination. Esterase is downregulated, and the pollen grain cells' extracellular matrix is physically and biochemically altered [2].

18.2.2.1.3 Copper Nanoparticle

Copper (Cu) is a crucial component needed for healthy plant development. In plants, it serves both a structural and practical purpose. It is a micronutrient whose mobility and bioavailability in the soil determine how much of it is present in the plant. Plants keep the concentration of copper in their various tissues at the ideal level. It participates in a number of internal mitochondrial and chloroplast processes. Protein trafficking, mitochondrial respiration, iron mobilization, hormone signaling, and cell metabolism are a few of its tasks. Plastocyanin contains a structural element called Cu. It promotes the production of hydrogen peroxide, a signaling molecule that enables plants to withstand or fend off stress. By giving the plant's cell wall strength, it lessens withering. Exogenous administration of Cu increases plant biomass production while also enhancing plant yield and quality. Cu shortage in plants interrupts the photosynthetic pathway and results in chlorosis, stunted growth, and curled leaves. When Cu is lacking, reactive oxygen species are formed more frequently. Both the motion of electrons along electron pathway and photosystems are affected. Additionally, Cu deficiency slows down the metabolism of carbohydrates and nitrogen [2].

18.2.2.1.4 Iron Nanoparticle

One of the important micronutrients needed for plant growth is iron. For various biochemical reaction, it serves as both a cofactor and a catalyst. It is necessary to regulate respiration and photosynthesis as well as to synthesis certain enzymes. Iron deficiency results in decreased synthesis of chlorophyll, which causes the leaves to turn yellow. The leaves develop chlorosis and necrosis as a result. Iron fertilizer application enhances plant growth and lessens the negative impacts of environmental conditions [20]. Nanofertilizer treatment helps to improve plant growth by reducing the negative effects of chemical fertilizer and their application using both the soil and foliar. Green synthesis of FeNPs is carried out using plant extract. The commonly used plants are *C. sinensis*, *A. indica*, and *Eucalyptus tereticornis* (Sm.). Plant extract's phytochemicals reduces the size of the Fe salt and keep the reaction stable. Iron oxide hydroxide, ferrous ferric oxide, ferric oxide, and iron mineral complex are among the FeNPs that are frequently used. When applied to stressed plants, FeNPs produce beneficial effects. Plants readily absorb them, and they lessen the ions' damaging effects. In *S. lycopersicum*, FeNP fertilization results in higher levels of phenol, vitamin C, and glutathione. The use of FeNPs causes the root membrane to selectively absorb certain chemicals. It lessens sodium absorption, which raises the potassium level in shoots and increases the plant's ability to withstand salinity. Due to their successful application to plant *in vitro* culture, the combination of FeNPs with salicylic acid generates drought tolerance traits in *F. vesca*. In comparison to untreated plants, FeNPs promote *T. aestivum* germination and lengthen the roots and shoots [2].

18.2.2.1.5 Sliver Nanoparticle

Silver ions are important for the development of shoots, roots, somatic embryos, and genetic changes. By using silver, plants produce less ethylene, which lowers their risk of chlorosis and chlorophyll destruction. Additionally, it increases the generation of metabolites (secondary), slows the aging process, and boosts crop growth and grain yield. The chemical content, surface reactivity, and velocity of application of nanoparticles all have an impact on how well they perform in plants. A high concentration of nanoparticles causes damaging effects. At the same time, the appropriate dose develops a positive response in plants, and the amount of dose is linked with the type of plant species. Nanoparticles are more effective, as documented in the literature. Aldehydes, ketones, flavonoids, tannins, carboxylic acid, amides, and terpenoids are some of these metabolites. Boiling the leaves of *Citrus sinensis* (L.) Osbeck, *Syzygium cumini* (L.) Skeels, *Centella asiatica* (L.), and *Ocimum tanuiflorum* L. produced an extract that was progressively added to a solution of silver nitrate (1 mM) [21].

18.2.2.1.6 Chitosan Nanoparticles

Chitosan is actively involved in the biochemical and molecular processes in plant cells, according to research on the effects of chitosan nanofertilization on *in vitro* seed germination. These mechanisms produce a number of biomolecules that help plants develop and protect them from a range of biotic and abiotic stresses. To better understand the plant's biochemical reaction to chitosan nanofertilization. Sharma *et al.* [22] applied a chitosan nanofertilizer for seed treatment and as a foliar spray and greatly boosted plant-growth metrics in maize plants including water, bulk chitosan, sulfuric acid, and copper sulfate. These findings demonstrated that a nanofertilizer at concentrations ranging from 0.01% to 0.16% has a stimulatory effect on all measures of plant development, including plant height, root length, root number, and stem diameter. Chitosan nanocomposites (LCNFs) were made by combining chitosan with lignocellulose nanofibers, activated carbon nanoparticles, and non-activated carbon nanoparticles. Chitosan nanocomposites gave the Dendang paddy variety the best growth patterns in a germination test, while in a greenhouse test, the Indragiri paddy variety displayed the finest development patterns. On mycorrhiza and fungus, all of the chitosan nanocomposites demonstrated a synergistic biofertilizing effect. Chitosan nanocomposites can be used as a growth regulator for specific types of peat-land paddy and to hasten the rehabilitation of peatlands in tropical areas [18].

18.3 Nanobiofertilizer Preparation

A combination of nanoparticles and biofertilizers is referred to as nanobiofertilizer. The slow release of nutrients by nanoparticle can improve the efficiency with which plants utilize nutrients. It can change the physical, chemical, and biological characteristics of the soil in a way that will improve its attributes over time. Encapsulating of nanoparticles with biofertilizer is the procedure used to create nanobiofertilizer. The product shields the bacterial strains from mechanical stress, and the nutrients are released gradually, which increases the product's effectiveness. Biofertilizer cells are inserted into the nanomaterial capsule using the encapsulation technique. This technique combines calcium alginate, a non-toxic, biodegradable substance, with starch. When used as a growth medium for rice seedlings grown in tropical climates, starch accelerates the growth of some bacterial strains [23].

Nanobiofertilizer can also be created using microcapsules. Plant growth-promoting rhizobacteria (PGPR) solution, 1.5% sodium alginate, 3% starch, and 4% bentonite must be mixed in a ratio of 2:1 to make it. The combination is then covered with the crosslinking calcium chloride solution after the microcapsules have been cleaned in sterile distilled water [2]. Nanobiofertilizer has also been created using salicylic acid and nanoparticles. This method involves adding sodium alginate (2%), ZnONPs (1 g/ml), and salicylic acid (1.5 mM) to the biofertilizer. 1-mm beads are created, air dried, and incubated at 4°C after the solution is covered with calcium chloride (3% solution) [24]. A study asserts that by combining organic waste from plants, animals, and even food waste with nanoparticles, a potent nanobiofertilizer that increases soil fertility can be created. Small pieces of organic waste were degraded, cleaned with water to remove impurities, and either pyrolyzed or left to decay. This garbage that had been partially broken down or pyrolyzed was mixed with nanoparticles to generate nanobiofertilizer [2].

18.4 Nanobiofertilizer and Soil Fertility

The employment of non-chemical compounds in farming operations has been shown to improve soil biodiversity and validate food safety. Utilizing the soil microflora, which is made up of different PGPRs, is essential to organic farming. Through the solubilization of phosphate or potassium, fixation of nitrogen, synthesis of antibiotics, release of chemicals that regulate plant growth, and biodegradation of soil-organic matter, biofertilizers help retain the micro and macronutrients in the soil. The use of biofertilizers contributes to soil erosion reduction by enabling mycorrhizal hyphae to hold soil masses together and strengthen the soil structure. Applying biofertilizers as seeds or soil inoculants causes them to multiply, which improves crop output by promoting nutrient cycling [25].

18.5 Response of Plant to Nanobiofertilizer

Plant growth is considerably accelerated by the use of nanobiofertilizer. The continuous and delayed release of nanoparticles into the plant's rhizosphere is caused by the coating of nanoparticles with biofertilizers, which increases the efficacy of biofertilizers. They keep fertilizer from leaching and maintain fertilizer solubility [2]. By enhancing the production of secondary metabolites like phenols and flavonoids as well as enzymatic antioxidants like catalase, superoxide dismutase, and peroxidase, they also enhance crop quality. These metabolites give fruits and vegetables a longer shelf life and have several advantageous health impacts [24].

When applied to plants, biofertilizer containing nanoparticles has improved effects because of their complementary mechanisms of action. Different plant systems responsible for improved plant growth and yield are activated by it. Additionally, they limit or restrict the growth of pathogens around the plant rhizosphere and lessen the negative impacts of harmful substances. Nanobiofertilizers supply vital nutrients in the soil while assisting in bioremediation. They lessen ROS' detrimental effects on plants, upregulate the genes that produce antioxidants, osmolytes, and stress-related proteins, and preserve cell structure and function. Additionally, they maintain the heightened hormonal synthesis and functions of membrane transporters. These treatments cause the plants' antioxidant mechanisms to activate, shielding the organelles and cell membrane from the damaging effects of stress. Additionally, they produce fewer stress hormones (such as abscisic acid) and more growth hormones, such as indole acetic acid and cytokinin. These modifications boost the plant's capacity to withstand stress and its likelihood of successfully establishing a crop in harsh environmental conditions [2].

18.6 Setback and Impact of Nanofertilizer in the Framework of Sustainable Agriculture

Recent advancements in technology have made it possible for nanofertilizers to increase agricultural yields. Nevertheless, there could be a number of unanticipated and long-lasting consequences from the deliberate application of this technology in agricultural operations. Within this setting, new health and environmental safety concerns may limit the use of modern technology in horticulture crop production, various nanoparticles have varied effects on plant growth. Nanomaterials can enter the plant through adhering to organic molecules in the surrounding environment, attaching to carrier proteins, aquaporin, iron channels, endocytosis, or forming new pores. The significantly thick seed coat that covers the entire seed is hypothesized to make it more difficult for nanoparticles to enter seeds than plant cell walls and membranes. A modest concentration of nanoscale SiO_2 and TiO_2 increased germination and plant growth in soybeans (Glycine max). To fix N_2, nano anatase is employed. In N-deficient conditions, spinach growth was enhanced by exposure to TiO_2. Nano anatase TiO_2 could either directly chemisorb N_2 or reduce it to NH_3 in spinach leaves when exposed to sunlight, turning it to organic nitrogen and promoting spinach growth. The ongoing weathering and reorganization of the soil's geogenic constituents, as well as strong biological activity, have resulted in an abundance of natural nanoparticles in the soil. Due to their highly reactive nature, manufactured nanoparticles may accumulate in the land and aquatic region, and waste bodies through extensive and uncontrolled use, resulting to the soil physio-chemical and biological characteristics been altered. Investigating the effects of released nanomaterial on soil microbes exposed to nanofertilizer manufacturing as well as application in the field, is therefore crucial. It is important to look into the viability and utility of these innovative smart fertilizers. In fact, their use in horticulture and sustainable agriculture is constrained by issues with toxicity, transportation, and bioavailability, as well as unanticipated natural consequences from contact with biological systems. Numerous variables, including dose, application technique, species, and the type of nanoparticles utilized, affect how much nanoparticles are ingested by plants as well as how they are transformed, translocated, and accumulated (phytotoxicity). Examining the level of toxicity of each nanoparticle in each individual crop is necessary in order to study the uptake and translocation of nanofertilizers as well as their activity in the plant and soil environment [6]. Figure 18.2 shows an overview of proteomics techniques.

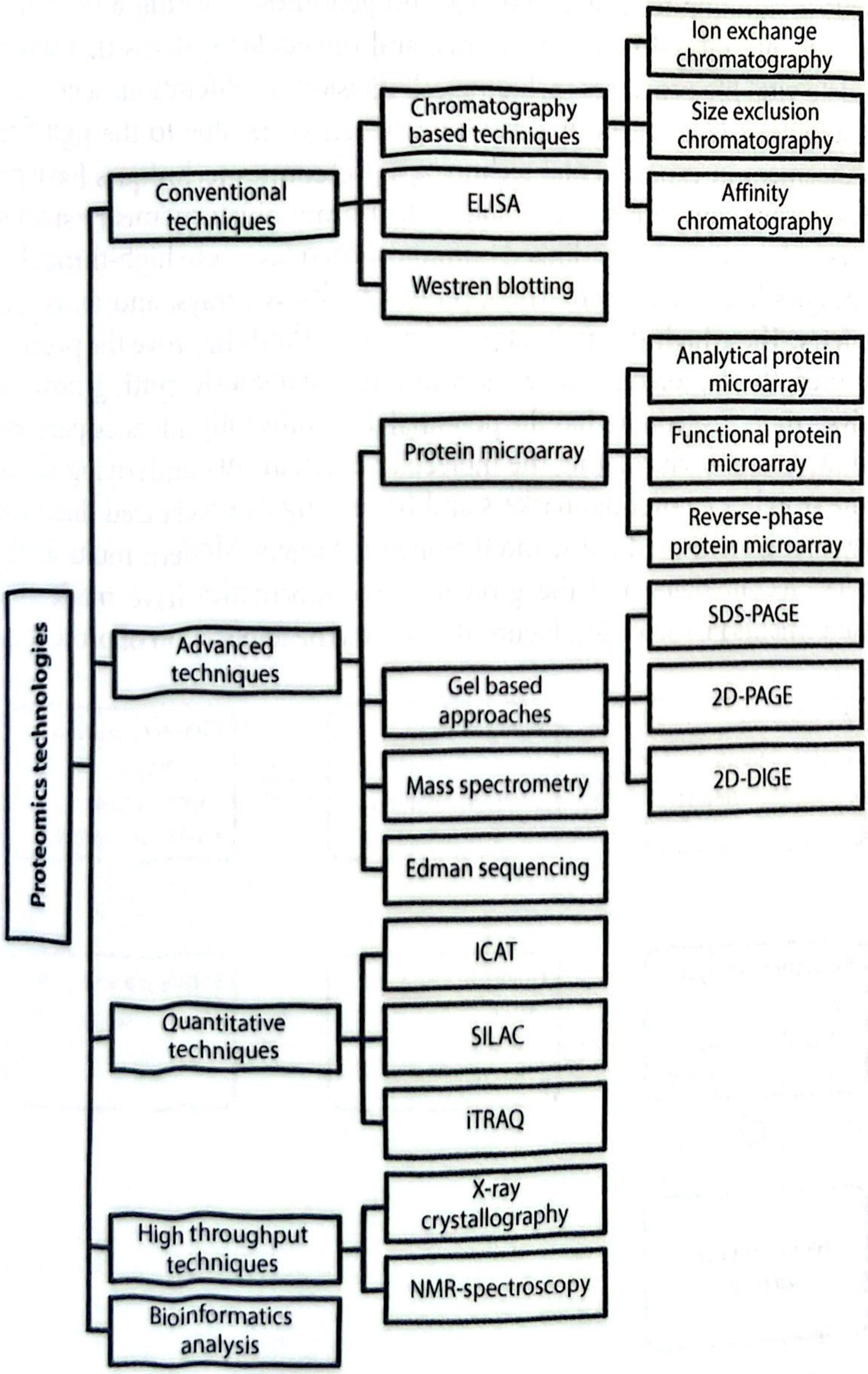

Figure 18.2 An overview of proteomics techniques.

18.7 Biotechnology Tools Used in Agriculture

18.7.1 Proteomics

Proteomics is the comprehensive study of protein structure, expression, interactions, modification status, composition, and links between proteins by a combination of data analysis and proteome experiments. It offers more details in addition to transcriptomics and genomes. Creating a map of the intricate, interrelated routes, networks, and molecular systems that directly regulate vital life processes including cell division, proliferation, senescence, and apoptosis is also crucial. Over the past ten years, due to the significant advancement in experimental technology, proteomics techniques have progressed from conventional techniques like immunohistochemistry staining, western blots, and enzyme-linked immunosorbent assays to high-throughput techniques like tissue microarrays, protein pathway arrays, and mass spectrometry. These high-throughput proteomics methods improve the precision and breadth of proteome coverage while simultaneously cutting down on analysis time. Proteomics has the potential to significantly advance personalized medicine by elucidating the molecular mechanisms underlying disease in the search for novel biomarkers and by serving as specialized diagnostic assays, prognostic predictors, and therapeutic targets. Modern multi-analyte "omics" technologies and the growth of bioinformatics have made these advancements possible [26]. Figure 18.3 shows the application of proteomics.

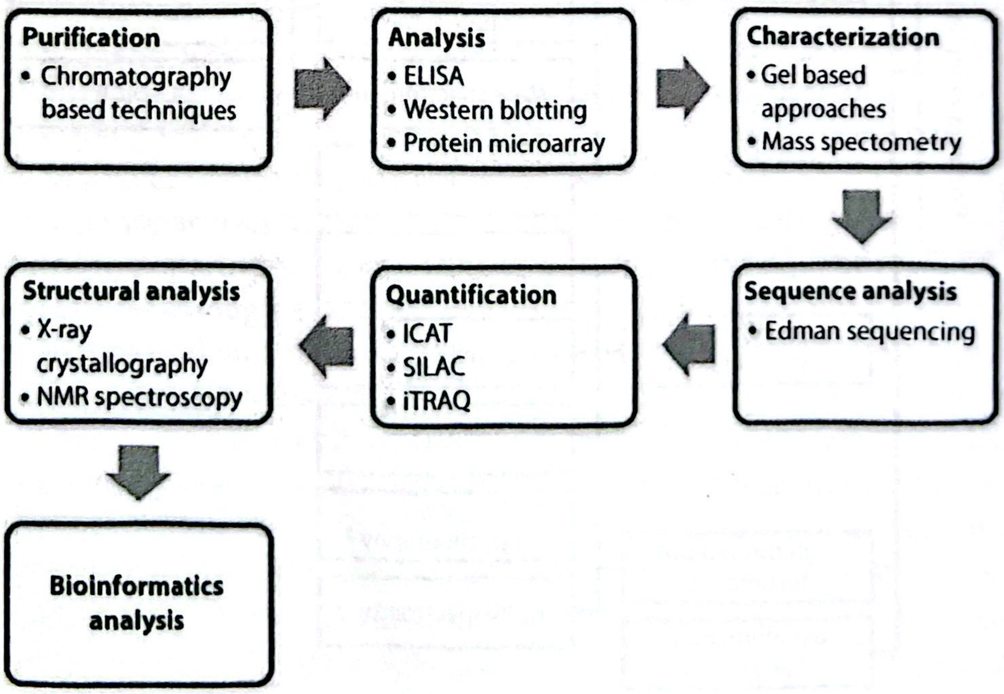

Figure 18.3 Application of proteomics [27].

18.7.1.1 Proteomics in Agriculture

It has been made possible by proteomics to identify a large variety of proteins that are essential for preserving crop health, increasing crop tolerance to stresses, and enhancing product quality. Researchers can monitor how crops respond to challenging environmental conditions or even forecast the nutritional content of crops thanks to the characterization of certain genes. Targeted genes may express themselves differently depending on the environment, and these variations can now be found. Because mass spectrometry (MS) is becoming an essential tool for examining protein post-translational modifications (PTMs) and protein interactions, the development of MS-based proteomics systems has been referred to as "new genomics". One particular benefit of proteomics over other "omics" methods is its capacity to demonstrate PTMs, which is required to ascertain the functional influence of protein modification on agricultural plant output [28].

18.7.2 Metabolomics

The study of a cell type, tissue, organ, or organism's metabolite composition, or metabolome, is known as metabolomics. The metabolome is a group of inorganic tiny molecules that serve as distinctive cellular biochemistry fingerprints. Metabolomics, which examines huge sets of low-molecular weight metabolites, provides a "snapshot" of significant biological processes. In relation to hereditary characteristics, gene expression, or environmental influences, it provides a readout of the status of metabolic activity. Such external stimuli include infections and allergies, where a unique metabolome profile identifies the gene-environment interaction (deoxyribonucleic acid (DNA), ribonucleic acid (RNA), proteins, lipids, and other enzymes) between the environmental agent and host molecules. Xenobiotics, food, and other foreign sources can all be converted into metabolites in addition to those that are directly created by the host organism. Metabolomics, the final component of the omics tetralogy, provides the opportunity to address questions that previous omics technologies are unable answer. Information on what might be occurring in a cell (the most likely cause of a phenotype), processes that are controlled by epigenetic regulation, and post-translational modifications can be found in the field of proteomics and genomics, which spans the spectrum from genomics to proteomics. Metabolomics provides a picture of the host's general physiology and response to the environment, which can be connected to the result phenotype (for instance, healthy *vs.* ill) and endotypes [29]. Figure 18.4 shows tetralogy of omics.

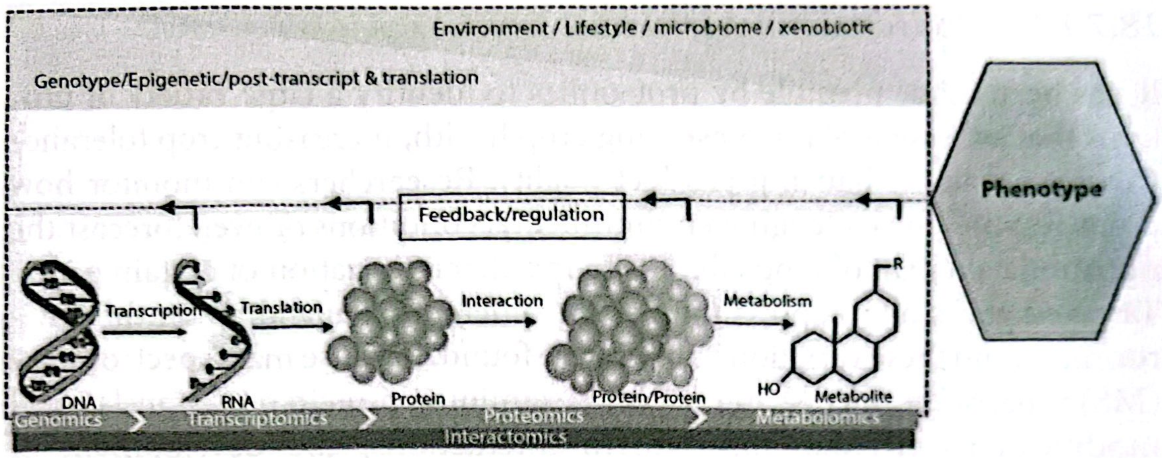

Figure 18.4 Tetralogy of omics [29].

Metabolomics has succeeded in establishing itself as a field of study that is crucial and complementary to proteomic, genomic, and transcriptomic investigations in recent years. Metabolomics is a crucial addition to genomic research, and its findings may form the basis for genetic improvement based on crop chemical composition, whether for nutritional or functional reasons, or because certain chemical compounds may contribute to some plant species' resistance to the previously mentioned factors.

18.7.2.1 Metabolomics in Agriculture

Metabolite content has a direct impact on a variety of agricultural activities, including fruit maturity, resistance to harmful environmental influences, stress-related issues, and pathogen attack. Analytical techniques, some of which are specific to particular chemicals, are used to analyze a variety of substances. For example, coenzymes, phenylpropanoids, polyketides, terpenoids, amino acids, amines, lipids, carbohydrates, phenolic compounds, alkaloids, and vitamins (hydrophilic and hydrophobic) can all be analyzed using liquid chromatography coupled with mass spectrometry. Due to the types of chemicals that gas chromatography mass spectrometry (GCMS) can analyze, fewer compounds can be analyzed; however, by applying derivatization procedures, the number of metabolites discovered by this technology grows significantly. This method makes it simple to analyze terpenoids, alkaloids, monosaccharides, steroids, essential oils, and fatty acids, among other substances. There are currently numerous instances of metabolomic research being used in agriculture for a variety of objectives. The following are some of the primary goals of metabolomic research in agriculture: the metabolic reactions to any kind of stress, the creation of metabolic profiles for genetic mapping, and the investigation of the influence of heredity. To determine the effects of place and season, investigate the phenotypic effects of natural plant species changes, assess transgenic cultivars, investigate metabolic variations among cultivars, and perform functional characterizations. Identify cultivars, clarify biosynthetic pathways, examine metabolic changes throughout growth, development, and differentiation, perform chemotaxonomic analysis, and study population differentiation [30].

18.7.3 Genomics

Genomic research entails a thorough investigation of gene families. These groups could include the entire gene pool of one creature or a number of them. The entire genetic makeup of an organism is referred to as its "genome." Consequently, genetic research is a component of genomics. The field of genomics can be divided in a number of ways. For instance, in comparative genomics, the genomes of several organisms are compared. Comparative genomics can be used to define important structural sequences that are shared by many genomes and to spot evolutionary changes in various genomes. Structural genomics discusses the physical characteristics of genomes as well as their sequencing and mapping. Studying the expression and operation of the genome is a component of functional genomics. Another component of genomics is the investigation of interactions between genes and between genes and the environment.

18.7.3.1 Genomics in Agriculture

Advances in genetics may hasten the creation of crops with promising agronomic characteristics. Agriculture genomics is the use of genetics to increase the productivity and sustainability of plants and animals. Genomic resources like expressed sequence tags (ESTs), BAC end sequences, genetic sequence polymorphisms, gene expression profiling, whole-genome sequencing, and genome-wide association studies have grown substantially by combining conventional and high-throughput sequencing platforms. We are moving away from single gene studies and toward whole-genome analyses, which provide a more comprehensive understanding of how all genes interact, as a result of the development of genomic sequencing and the increase of bioinformatic tools. This special issue aims to highlight current advances in comparative genomics for plant breeding, transcriptome analysis for plant breeding, genotyping and marker-assisted breeding, and recombinant DNA technologies. Eleven original research papers as well as three reviews make up this collection.

18.7.4 Bioinformatics

Bioinformatics can be summed up as "the application of computational tools to organize, analyze, understand, visualize, and store information associated with biological macromolecules" due to its multidisciplinary nature. Dinz & Canduri, [31] provides a summary of the bioinformatics and genomics sciences from three angles: the fundamental idea of molecular biology is the cell. The organism is the second area of attention from this approach, displaying variances across distinct developmental phases and physiological regions. The author highlights a global viewpoint in his final sentence: iii) the tree of life, which contains three evolutionary branches made up of millions of different species. Many authors present a computational perspective. These authors list the following as the goals of bioinformatics: it is important to 1) organize data so that scientist can access it and add new entries, 2) create tools and resources to help with data analysis, and 3) use these tools to examine the data and interpret it in a useful way. The issues with bioinformatics can be divided into two categories: those involving sequences and those involving biomolecular structures [31].

18.7.4.1 Bioinformatics in Agriculture

The science of agricultural genomics, or agri-genomics, depends increasingly on bioinformatics for the gathering, storage, and analysis of genomic data. Two examples of the numerous bioinformatics tools and methods used in agriculture that are referred to as "agri-informatics," a broad term embracing a number of applications, are enhancing plant tolerance to biotic and abiotic stimuli and enhancing nutritional quality in depleted soils. Along with these objectives, gene discovery through computer software has allowed researchers to create focused strategies for enhancing seed quality, giving plants extra micronutrients for better human health,

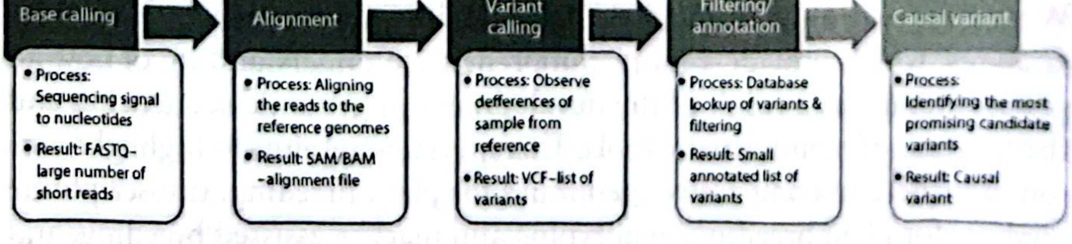

Figure 18.5 Next-generation sequencing bioinformatics workflow [32].

and developing plants with phytoremediation skills [34]. Figure 18.5 shows the next-generation sequencing bioinformatics workflow.

18.8 Present Status of Nanobiofertilizer Research and Application

Due to the speedy results they offer, researchers are growing more interested in using nanoparticles in agriculture. The creation of intelligent fertilizer using nanoparticles and other substances has been studied, although nothing is known about it. A few articles on the creation and application of nano-biofertilizer have recently been published; this is a step toward the creation of a brand-new and improved crop-care product. Iran developed nanobiofertilizer that boosted proline, glucose, and anthocyanin levels in *Hibiscus sabdariffa* and *Foeniculum vulgare* under drought stress [2]. Akhtar *et al.* [2] conducted their research in Pakistan to demonstrate how the application of PGPR and Ag NPs together boosts the weight of *Allium cepa* when it is exposed to excessive salinity. Additionally, they noted that plants' sugar content and the expression of a few novel proteins both rose as a result of the co-application. Plants receiving the combination treatment of PGPR and Ag NPs also had high levels of phenolic, carotenoid, flavonoid, and chlorophyll content. The use of nano-gypsum and *Pseudomonas taiwanensis* in India increased soil moisture, increased nutrient availability, and boosted bacterial diversity and growth. The activities of soil enzymes were also improved by the use of this nanobiofertilizer. In place of agrochemicals, nano-gypsum can be employed to improve soil structure and sustain the bacterial population. *Pseudomonas taiwanensis* and nano-gypsum work together to improve *Zea mays*' germination, root length, shoot length, and chlorophyll content [33]. Additionally, Indian researchers have demonstrated that the usage of nano-chitosan increased the number of PGPR colonies. They work together synergistically to enhance *Z. mays*' germination and growth characteristics. Nanocomposite biofertilizer enhanced plant biomass, crop productivity, and plant resistance to biotic stress in *Triticum aestivum* and *Cicer arietinum* [2].

There are numerous locations across the world where nanobiofertilizer is being created. However, more research is required to understand the molecular effects of nanobiofertilizer on plants. However, a suitable nanobiofertilizer must still be created on a wide scale, and it must be made available for purchase.

18.9 Application of Biotechnology Tools for Nanobiofertilizer Improvement

The strains are evaluated for effectiveness in a greenhouse experiment prior to field testing and application in order to choose the inoculum for the production of nanobiofertilizer. The mechanisms and procedures by which the strains promote plant growth are looked at in this step. Bioinformatics and molecular techniques including as genomics, metabolomics, proteomics, and transcriptomics have made it possible to compare the capacity of inoculant strains to stimulate plant development [35]. Such information can be used to create nanobiofertilizer that will function well in a variety of agricultural settings. For instance, as molybdenum is necessary for N-fixation, it might be included in N-fixing inoculants and used in soils with low molybdenum levels [7].

Utilizing desired genes to promote the expression of biofertilization functions, genomic engineering techniques might also be used to modify naturally occurring beneficial bacteria. This would enable the development of improved strains with a variety of field functions [7].

Numerous state-of-the-art bioinformatics and computational science tools are connecting crop proteomics with other "-omics," and physiological data is further opening up new avenues for crop improvement studies via the signaling, regulatory, and metabolic networks underlying plant phenotypes. In integrated "omics" techniques, crop proteomics is projected to be essential [28].

Applying metabolomics to nanobiofertilizer to nanofertilizer offer insight into the metabolites present and their concentrations, allowing researchers to evaluate the impact of nanobiofertilizer on plant metabolism, nutrient assimilation and growth promotion, via this, researcher can optimize the formulation of nanobiofertilizer to ensure the delivery of specific metabolites, thereby improving their efficacy. The mechanisms of the drought response have been extensively studied using proteomics and metabolomics in the leaves of triticale (*Triticum durum*), maize, and rice (*Oryza sativa* L.). There is still disagreement on the merits of using two different nitrogen treatment techniques to manage rice's drought stress response. Proteomics, metabolomics, and associated physiological indices have been used to study the mechanisms of high nitrogen treatment before and after drought mitigation rice yield loss. Two nitrogen management strategies were utilized in this study on the rice variety Wufengyou 286 as the experimental subject: heavy nitrogen application before drought (NBD) and heavy nitrogen application after drought (NAD). The time period for drought therapy was chosen to be the young panicle differentiation stage. The physiological index, proteomics, metabolomics analysis, and yield were examined to determine the efficacy of NBD and NAD in reducing drought on the loss of rice production. This provides a theoretical road map for managing the nitrogen regulation of rice grown during a drought [22].

An alternative technology that enables researchers to monitor the modifications and regulation of genes that have wide geonome under specific biological situations is the use of bioinformatics scanning approaches. As their final products, these high-throughput methods typically produce sizable gene or biological research interest lists. When compared to older conventional biological research, where we might investigate one or a few genes at a time, bioinformatics has unquestionably shortened the time-consuming experimental process, which is significantly reducing the overall time required for nanobiofertilizer research [22].

Changes to an organism's DNA are made through gene editing, one of the primary methods for which is the usage of Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-associated protein 9, which has been shown to be more accurate and effective than other gene editing techniques. Researchers recently created nanoparticles with the capacity to transmit the CRISPR-Cas9 system [36].

18.10 Conclusion

The application of proteomics, metabolomics, genomics and nanobiofertilizer research can give a comprehensive knowledge about the molecular mechanisms underlying plant microbe interaction, nutrient delivery and crop growth promotion. This knowledge can be exploited to optimize the composition and functionality of nanobiofertilizers, resulting to improved crop productivity, nutrient use efficiency, and environmental sustainability.

References

1. Yadav, N.A., Kour, D., Yadav, N., Nano-biofertilizers for Agricultural Sustainability. *J. Appl. Biol. Biotechnol.*, 11, 5, 1–5, 2023, http//doi.org/10.7324/JABB.2023.162662.
2. Akhtar, N., Ilyas, N., Meraj, T.A., Pour-Aboughadareh, A., Sayyed, R.Z., Mashwani, Z.-u.-R., Poczai, P., Improvement of Plant Responses by

Nanobiofertilizer: A Step towards Sustainable Agriculture. *Nanomaterials*, 12, 965, 2022, https://doi.org/10.3390/nano12060965.

3. Kumari, R. and Singh, D.P., Nano-biofertilizer: An emerging eco-friendly approach for sustainable agriculture. *Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.*, 90, 4614, 733–741, 2020, http//doi.org/10.1007/s40011-019-01133-6.
4. Mala, R., Celsia, A.V., Bharathi, S.V., Blessina, S.R., Maheswari, U., Evaluation of nano structured slow release fertilizer on the soil fertility, yield and nutritional profile of *Vigna radiate*. *Recent Pat. Nanotechnol.*, 11, 50–62, 2017.
5. Fatima, F., Hashim, A., Anees, Efficacy of nanoparticles as nanofertilizer production: a review. *Environ. Sci. Pollut. Res.*, 28, 2, 1292–1303, 2021.
6. Ilmudeen, S., Farween, F., Mahaletchumi, S., Kanchana, D.K.D., II, Advances of Nanofertilizers in Modern Agriculture; A review. *J. Res. Technol. Eng.*, 3, 2, 19–29, 2022.
7. Raimi, A., Roopnarain, A., Adeleke, R., Biofertilizer production in Africa: Current status, factors impeding adoption and strategies for success. *Sci. Afr.*, 11, 2012, 1–20, 2021, http//doi.org/10.1016/j.sciaf. 2021.e00694.
8. Adeleke, A.R., Raimi, R.A., Roopnarain, A., Mokubedi, M.R., Status and prospects of bacterial inoculants for sustainable management of agroecosystems, in: *Biofertilizers Sustain. Agric. Environ., Soil Biolo*, B. Giri, R. Prasad, Q.-S. Wu, A. Varma (Eds.), pp. 137–172, Springer, Cham, 2019, doi: 10.1007/978- 3- 030- 18933- 4.
9. Thomas, L. and Singh, I., Microbial biofertilizers: types and applications, in: *Biofertilizers Sustain. Agric. Environ*, vol. 55, B. Giri, R. Prasad, Q. Wu, A. Varma (Eds.), pp. 109–135, Springer Nature, Switzerland AG, 2019, http//doi.org/10.1007/978- 3- 030- 18933- 4 _ 1.
10. Kumar, S., Diksha, Sindhu, S.S., Kumar, R., Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Curr. Res. Microb. Sci.*, 20, 3, 100094, 2021, https//doi.org/10.1016/j.crmicr.2021.100094.
11. Liffourrena, A.S. and Lucchesi, G.I., Alginate-perlite encapsulated *Pseudomonas putida* A (ATCC 12633) cells: preparation, characterization and potential use as plant inoculants. *Asian J. Biotechnol.*, 278, 28–33, 2018.
12. Mushtaq, Z., Faizan, S., Hussain, A., Role of Microorganisms as Biofertilizers. In *Microbiota and Biofertilizers*, pp. 83–98, 2021, https//doi.org/10.1007/978-3-030-48771-3_6.
13. Kumar, A., Singh, R., Giri, D.D., Singh, P.K., Pandey, K.D., Effect of Azotobacter chroococcumCL13 inoculation on growth and curcumin content of turmeric (*Curcuma longa* L.). *Int. J. Curr. Microbiol. Appl. Sci.*, 3, 9, 275–283, 2014.
14. El-Sayed, W.S., Akhkha., A., El-Naggar, M.Y., Elbadry, M., *In vitro* antagonistic activity, plantgrowth promoting traits and phylogenetic affiliation of rhizobacteria associated with wildplants grown in arid soil. *Front. Microbiol.*, 5, 651, 2014.

15. Sandhya, V., Shrivastava, M., Ali, S.Z., Prasad, V.S.K., Endophytes from maize with plant growth promotion and biocontrol activity under drought stress. *Russ. Agric. Sci.*, 43, 22–34, 2017.
16. Bharti, N. and Kumar, A., Response of mycorrhiza on physiological and biochemical parametersof black gram *Vigna mungo* (L.) hepper. *IJPRBS*, 5, 2, 143–157, 2016.
17. Quddus, F., Recent advances in biofertilizer, 2021.
18. Bairwa, P., Kumar, N., Devra, V., Abd-Elsalam, K.A., Nano-Biofertilizers Synthesis and Applications in Agroecosystems. *Agrochemicals*, 2, 118–134, 2023, https://doi.org/10.3390/agrochemicals2010009.
19. Ali, N., Réthoré, E., Yvin, J.C., Hosseini, S.A., The regulatory role of silicon in mitigating plant nutritional stresses. *Plants*, 9, 1779, 2020.
20. Pourjamshid, S.A., Study the effect of iron, zinc and manganese foliar application on morphological and agronomic traits of bread wheat (Chamran cultivar) under different irrigation regimes. *Environ. Stress. Crop Sci.*, 14, 109–118, 2021.
21. Ahmed, R.H. and Mustafa, D.E., Green synthesis of silver nanoparticles mediated by traditionally used medicinal plants in Sudan. *Int. Nano Lett.*, 10, 1–14, 2020.
22. Sharma, K.R., Role of Bioinformatics in Various Aspects of Biological Research: A Mini Review. *Res. Rev.: Res. J. Biol.*, 2, 37–57, 2015.
23. Vafa, Z., Sohrabi, Y., Sayyed, R., Suriani, N.L., Datta, R., Effects of the combinations of rhizobacteria, mycorrhizae, and seaweed, and supplementary irrigation on growth and yield in wheat cultivars. *Plants*, 10, 811, 2021, http//doi.org/10.3390/plants10040811.
24. Panichikkal, J., Puthiyattil, N., Raveendran, A., Nair, R.A., Krishnankutty, R.E., Application of encapsulated *Bacillus licheniformis* supplemented with chitosan nanoparticles and rice starch for the control of Sclerotium rolfsii in *Capsicum annuum* (L.) seedlings. *Curr. J. Microbiol.*, 78, 911–919, 2021.
25. Singh, B., Upadhyay, K.A., Al-Tawaha, W.T., Al- Tawaha, R.A., Sirajuddin, N.S., Biofertilizer as a tool for soil fertility management in changing climate. *IOP Conf. Ser.: Earth Environ. Sci.*, 492, 2020, 012158, 2020, https//doi.org/10.1088/1755-1315/492/1/012158.
26. Cui, M., Cheng, C., Zhang, L., High-throughput proteomics: a methodological mini-review. *Lab. Invest.*, 102, 1170–1181, 2022, https://doi.org/10.1038/s41374-022-00830-7.
27. Aslam, I., Basit, M., Nisar, A.M., Khurshid, M., Rasool, H.M., Others, Proteomics: Technologies and Their Applications. *J. Chromatogr. Sci.*, 55, 1, 182–196, 2017, https://doi.org/10.1093/chromsci/bmw167.
28. Beyene, B., Gizachew, H., Temesgen, M., Habitamu, D., Review on Proteomics Technologies and Its Application for Crop Improvement. *Belachew Int. Inst. Sci. Technol. Educ. (IISTE): E-J.*, 7, 6, 2222–2871, 2016.
29. Turi, K.N., Romick-Rosendale, L., Ryckman, K.K., Hartert, T.V., A review of metabolomics approaches and their application in identifying causal

pathways of childhood asthma. *J. Allergy Clin. Immunol.*, 141, 4, 1191–1201, 2018, doi: 10.1016/j.jaci.2017.04.021.

30. Ibarra, E., Hernandez, M., Tenago, M., Metabolomics as a Tool in Agriculture. in: *Metabolomics-fundamentals and Applications*, pp. 147–168, 2016, http// doi.org/105772/66485.
31. Dinz, W.J. and Canduri, F., Review-Article Bioinformatics: an overview and its applications. *Genet. Mol. Res.*, 16, 1, 1–12, 2017, https//doi.org/10.4238/ gmrl1609645.
32. Filhart, D.M., Michael, L., Chih-Wen, O., Rajini, H., Jimmy, L., Computational and bioinformatics frameworks for next-generation whole exome and genome sequencing. *Sci. World J.*, 730210, 2013, https//doi. org/10.1155/2013/730210.
33. Chaudhary, P., Khati, P., Chaudhary, A., Maithani, D., Kumar, G., Sharma, A., Cultivable and metagenomic approach to study the combined impact of nanogypsum and *Pseudomonas taiwanensis* on maize plant health and its rhizospheric microbiome. *PloS One*, 16, e0250574, 2021.
34. Sriharsha, D. Nagarajan, N., Murthy, S., Nair, L., & Bagchi, P. (2023). Nano-informatics: Enhancing Crop Production with Application of Nanoparticles in Agriculture. https//doi.org/10.2991/978-94-6463-164-7_18.
35. Terra, L.A., De Soares, C.P., Meneses, C., Tadra Sfeir, Z.M., De Souza, E.M., Silveira, V., Vidal, S.M., Baldani, I.J., Schwab, S., Transcriptome and proteome profiles of the diazotroph Nitrospirillum amazonense strain CBAmC in response to the sugarcane apoplast fluid. *Plant Soil*, 451, 2020, 145–168, 2020, http//doi.org/ 10.1007/s11104- 019- 04201- y.
36. Usman, M., Farooq, M., Wakeel, A., Nawaz, A., Alam Cheema, S.A., Rehman, H.U., Ashraf, I., Sanaullah, M., Nanotechnology in agriculture: Current status, challenges and future opportunities. *Sci. Total Environ.*, 721, 137778, 2020.