Nano-agrobiotechnology: A step towards food security

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Over the years, the Indian system of agriculture has permitted widespread adoption of genetically improved new seeds, chemical fertilizers, pesticides, intensive irrigation, optimum agronomic conditions and modern machinery to only a few crops. Advances in breeding for crop improvement, higher nutrition, abiotic and biotic stress resistance, post-harvest preservation, etc. have met with limited success. Plant attributes conferring increasing yields under fast-deteriorating natural resource base have yet to be identified. Superposition of models, each with its own range of inaccuracies, amplifies the overall range of several uncertainties of projections. The country now faces the challenge of enhancing crop production and providing nutritionally adequate diets for the increasing population, under uncertain climatic extremes, water scarcity, in limited (and degraded at many places) land area, with more requirement of water, and in many cases with poor quality water and air, and rapid erosion of natural biodiversity.

For billions of years, natural biological processes have evolved predominantly as a self-assembly of atoms and molecules to form complex structures called 'cells' culminating in life forms. Inside the cells, there are microtubules (~25 nm dia), structurally linear polymers of tubulin associated with globular protein molecule, high molecular weight proteins (200–300 kDa) or the tau (20–60 kDa) proteins, with one domain bound to tubulin polymers or unpolymerized tubulin, and the other end bound to vesicles or granules. Protein microtubules help move vesicles, granules, organelles like mitochondria and chromosomes, and play a prominent role in cell growth, form and development, and the eventual shape of the cell, and ultimately the shape of the plant. They also serve a cytoskeletal role. Some of these tubules assemble spontaneously and act as girders supporting the cell, while others form tracks to transport cells.

In plants, microtubules emerge out in the cell wall in a random pattern. Over time, individual microtubules organize in large three-dimensional arrays at the cell periphery, and play an important role in the distribution of cellulose. Molecular reactions can form stronger and tougher products than the delicate biological cells, and molecular programming with genetic data can create more molecular structures. However, the detailed molecular structures and the mode of assembly are still unclear. Plant varieties/genotypes with novel traits for biotic and abiotic stress resistance, gene flow, impact on non-target organisms, in terms of their specific use and safety both for environment and for human health, may be produced by conventional breeding, mutagenesis, or more commonly, by recombinant DNA techniques.

Both prokaryotes and eukaryotes contain informational genes that are involved in processes like replication, transcription, translation, etc. and are difficult to transfer; as compared to the operational genes, which are primarily involved in metabolic cycles. In photosynthesis, microRNA strands regulate gene expression in plants and control basic organ development, mobilizing different interactions between atoms and molecules. DNA serves as a data-storage system, transmitting instructions to the ribosomes, which manufacture different kinds of protein molecules.

Hundreds of microRNAs exist in each species of plant, but the functions of only a few are understood. The gene transfer mechanisms remain largely unknown. Yet, tremendous progress has been made in practical implementation of transformation protocols for both dicotyledonous and monocotyledonous plants[1]. Particularly, extension of this methodology to monocotyledonous plants, due to genetic manipulation of economically important crops like cereals and legumes, and T-DNA is transferred to dicot and monocot plants by an identical molecular mechanism[1]. Nevertheless, new tools are needed, specifically designed for separation, identification and quantification of individual molecules, to explore the fundamental life processes.

Recently, nanotechnology has been attracting increased attention worldwide. Drexler[2] first coined the term 'nanotechnology' in 1981. It encompasses research and applications of assembling atoms and molecules into desired new systems, on atom-by-atom or molecule-by-molecule basis, incorporating specific features, with one or more critical dimensions measuring between 0.1 and ~100 nm (1 nm = 10^{-9} m). By comparison, a typical strand of DNA is only 2 nm wide and proteins are 1–20 nm in size.

Nanotechnology involves two crucial devices: the nanocomputer, which is a molecular machine capable of executing a string of instructions, and the nanoassembler, a device at the atomic level, which contains a nanocomputer in its core, and can precisely arrange atoms on an atom-by-atom basis and manufacture any desired form of molecules, as Atomic Force Microscopy uses electric fields to 'push' atoms into position. Development of the nano-assembler technology is quite similar to that of recombinant DNA technology, in which in every cell, the ribosomes copy DNA into RNA, and feed this RNA into the ribosomes, like many instructions being fed into a computer, and then gather the correct amino acids to create the proteins, which make up the physical nature. After the success of recombinant DNA technology, isolation and sterilization techniques helped in containing newly developed organisms.

The functional molecular components of living cells, protein or RNA, aggregates of molecules, and organelles, can be genetically altered with a specific sequenced DNA strand that would match the recipient's DNA. Since, for survival, all biological cells require glucose, which only allows the production of ATP, nanomachines would need not only glucose, but also molecules rich in iron, calcium and other metallic ions, so that the biological part of the 'cells' of the nanomachines can survive and reproduce. In the presence of light energy, nanomachines may be converted to chemical energy in the form of ATP, which can further produce ADP, phosphorus, and energy that can run the nanomachines. However, nanotechnology application in food and agriculture is in its nascent stage.

In the Indian context, although conventional biotechnological approaches have adopted genetic manipulation, relatively little efforts have been made to understand the thermodynamics of the complex molecular structures as related to their stability. Application of nanotechnology, microscopy and other physical instrumentation techniques in some of the key areas, such as fundamental genetics, cytology, cellular ultra-structure, molecular basis of plant and insect taxonomy, can be helpful in this direction to understand the relationship between microscopic properties and molecular structure in a variety of biological materials of plant and animal origin.

Examples of general areas of research include: biosensors for pathogen and contaminant detection; tools to extract and analyse genetic material from single or several cells, and generating starch or cell walls with different properties. Cellular systems may also offer a path to produce carbohydrates, and in particular, polysaccharides, which are otherwise difficult to synthesize by combined synthetic chemical and enzymatic routes. By developing new solvents for cellulose, high-strength fibre can be produced using electrospinning of nanofibres from cellulose, which could provide nanoscale pores. An array of millions of carbon nanofibres can be grown on various substrates, for altering the DNA content of a cell. By parallel microinjection technique, DNA can be directly introduced into the nucleus of a variety of cells, including those with rugged cell walls, such as plants and bacteria, to programme the cell to produce new proteins. A well-known example is golden jasmine rice[3], engineered for improved nutritional value.

New opportunities exist in nanofluidics and nanomembranes to segregate proteins or nucleic acids (DNA and RNA) based on size and shape, by passing a single DNA or RNA thread through a nanosized pore. Such nanofabricated tools in genomics and proteomics are likely to lead to higher throughput screening of biological structures or validation of genetically modified structures. Understanding the behaviour of microtubules may provide more insights about how herbicides actually act, and this could help in developing better herbicides. Protein design by changes in the structure of biosynthetic enzymes, or by insertion of new enzymes into the pathway can help in molecular manufacture. Nanotechnology tools could help detect convergence in pathogens and biosensors for improved and contamination-free food and agricultural products.

However, there is a need for public awareness about the advantages and challenges of nanotechnology and new applications of this technology. Despite controversies[4–6] on research in nanotechnology, it may be useful to confront the challenge of nanotechnology in a constructive manner, to enable us to peep into the nanoscale world of plants and to help in bridging the knowledge gaps for better understanding of the inherent complexities in the macro plant system. The history of science and technology suggests that every new idea is first ridiculed, then questioned and finally taken for granted. At this stage of helplessness due to fatigue in crop productivity, the choice remains between self-replicating nano-agrobiotechnology and self-replicating biotechnology in isolation.

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