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Nano Omics in Agricultural Sciences - Is It an Interdisciplinary Revolution or Just Another Theoretical Science

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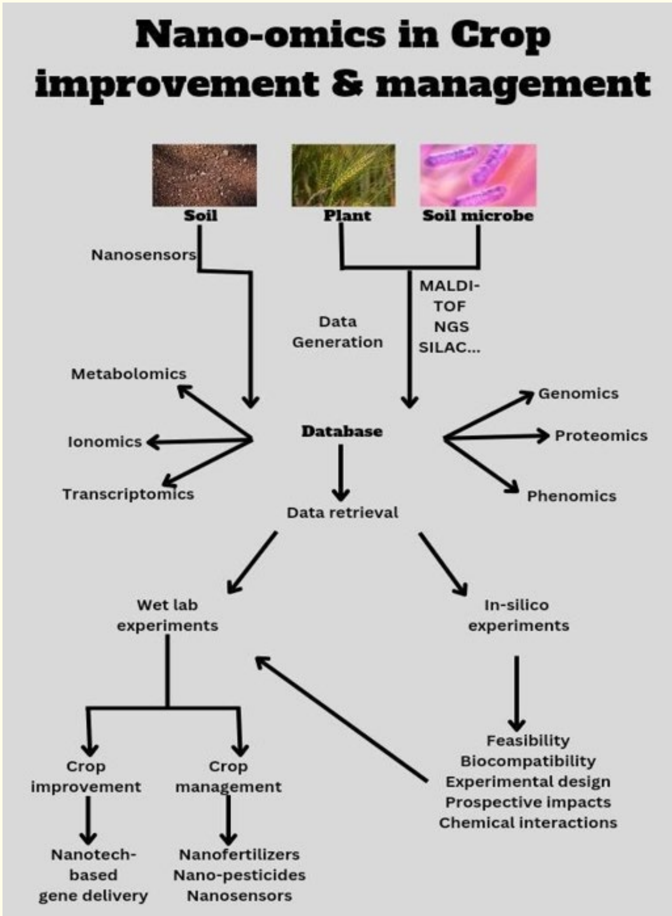
Abstract

With the current world population being at 8 billion and still counting, there is an urgent need to tackle the questions in food security, which can be answered by improvements in the various crop species and their sustainable management practices. These improvements can include the production of various stress resistant crops, that cause minimal resource exhaustion. Thus, in order to produce such novel crop strains, approaches such as Nano Omics can be employed. Also, introduction of certain properties and changes in certain metabolic pathways of plants can lead to them being much more suited for sustainable agricultural practices. Omics refers to the holistic approach of studying (quantifying, localizing, characterization) of all the essential components of a biological body, such as, genes, transcripts, proteins, and metabolites. The amalgamation of this knowledge with the emerging field of nanotechnology can bring about revolutionary amendments in the field of crop improvement and crop management, that would lead to better sustainable agricultural practices and food security. Omics technology (specifically, Genomics) has already enabled the development of crops like, drought tolerant maize, Flavr savr tomato, rice with higher grain production, etc. Besides, there has also been the use of engineered nanomaterials (ENMs) in precision agriculture to improve crop quality, nutritional value, pathogen resistance, and most significantly to improve crop resilience against extreme climatic conditions. Additionally, ENMs have been used in various crop management practices and experiments to detect nano-toxicity, or as carriers or active material in nano- enabled pesticides. Hence, employing these approaches would also help in the development of agricultural practices that are both sustainable and resilient to the ever-changing climatic conditions, but what one needs to understand is the abundance of such techniques which often remain unemployed due to lack of feasibility.

Keywords: Engineered nanomaterials; Nanotechnology; Nano-toxicity; Omics; Agriculture

Graphical Abstract



Introduction

As the world population has been on an exponential increase, there emerges various issues like food scarcity, concerns regarding use of chemical fertilizers and pesticides, that in turn result in pollution. This has a direct impact on the sustainable growth of each country and hence, degrades our planet's health. To combat such challenges against sustainable development, there are various MoUs, COP summits, and pledges being taken by the countries across the globe. One of the key areas of focus in such circumstances can be the promotion of sustainable agricultural practices by discovering the nexus of nanotechnology and omics, i.e., Nano-omics.

As we know, Nanotechnology is concerned with the "engineering, production and use of structures that are at a one-billionth of a metre/nanometre scale" [1], whereas Omics refers to the "comprehensive study of all the genetic material (genomics), proteins (proteomics), transcriptomes (transcriptomics), metabolism (metabolomics) in a living system". The amalgamation of these two avenues is being referred to as nano- omics, which deals with the study, design, and production of ENPs (Engineered Nanoparticles)/ENMs after studying all the -omics of the organism to achieve goals like precise and targeted drug delivery, accurate incorporation of genes of interest, modification of plants to produce desired yield, reduction of the burden of using chemical fertilizers, etc. Although at a very nascent stage, nano-omics has shown researchers some promising results that might be a way forward in the field of crop improvement and management to achieve the target of sustainable agriculture and food security. Thus, in this article we try to draw the limelight on certain techniques of crop improvement and management, use of nanotechnology and omics in crop improvement, the significance of nano-omics, research gap and certain future prospects of this field.

Sl. No.	*Terminology*	*Detail*
1.	ENMs	Engineered Nanomaterials
2.	Nano-toxicity	Generation of toxic biological responses by nanostructures [2]
3.	Genomics	It is that subfield of omics that is concerned with all the data regarding the entire genetic content of an organism [3]
4.	Proteomics	Subfield of omics, concerned with the study of the entire protein content of a biological system [4]
5.	Phenomics	Discipline concerned with the characterization of phenotypic effects of underlying genes and their mutations and alterations [5]
6.	Transcriptomics	Subfield of omics, concerned with the study of all the RNA transcript content (transcriptome) of a biological system [6]
7.	Metabolomics	Subfield of omics, concerned with the study, identification, and quantification of all the metabolic pathways and metabolite content (metabolome) of a biological system [7, 8]
8.	Ionomics	Subfield of omics, concerned with the study, identification, and quantification of all the chemical elements that accumulate in a living system [9]
9.	Lipidomics	Study and analysis of lipids and molecules interacting with lipids, along with lipid detection and their characterization [10, 11]
10.	Microbiomics	It is the study, identification, and quantification of all the microbial cells present in a defined region that can range from epithelial tissues to human gut to the rhizosphere of a plant [12]
11.	Glycomics	Scientific discipline that is concerned with the identification and functioning of all the glycan molecules in a living system [13]
12.	Epigenomes	It refers to all the modifications/changes that are present in the genomic DNA of a living system [14]
13.	ENPs	Engineered Nanoparticles
14.	NPs	Nanoparticles
15.	TALEN	Transcription-activator like Effector Nuclease; simply put, they are proteins that have been derived from Xanthomonas (a plant pathogenic bacteria) and are now being utilized in crop improvement programmes [15]
16.	Zn Finger Nuclease	These are nucleases that have been modified to contain Zn finger DNA- binding domain and are used as tools to carry out gene alterations [16]
17.	CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats; It is a characteristic bacterial defence system now used as a genome editing tool
18.	Panomics	It refers to the analysis carried out on multi-dimensional omics data [17]
19.	Multi-omics	It is the integration of multiple omics subfields
20.	NGS	Next Generation Sequencing; it is a DNA sequencing technology [18]

21.	2D-PAGE	Two-Dimensional Polyacrylamide Gel Electrophoresis
22.	LC-MS	Liquid Chromatography-Mass Spectroscopy
23.	GC-MS	Gas Chromatography-Mass Spectroscopy
24.	MALDI-TOF MS	Matrix-Assisted Laser Desorption Ionisation-Time of Flight Mass Spectroscopy
25.	SILAC	Stable Isotope Labelling by Amino acids in Cell culture; it is a quantitative technique used in proteomics [19]
26.	Isotope-coded affinity tagging	Technique used in quantification and sequence identification of individual proteins from a mixture [20]
27.	NMR	Nuclear Magnetic Resonance Spectroscopy
28.	Ensembl Plants	Database concerned with plant genome data
29.	KEGG	Database and software concerned with understanding and simulating the functional behaviours of a living system by deciphering its genome information [21]
30.	MetaCyc	It is a metabolic pathway database [22]
31.	Reactome	It is a tool for viewing the metabolic pathways and analysing their data [23]
32.	ProteomicsDB	Database storing protein data generated using mass spectrometry [24]
33.	PRIDE	Proteomics Identifications Database
34.	Paintomics	It is a web-based tool for simultaneous analysis of transcriptomics and metabolomics data [25]
35.	3Omics	It is a web-based tool for simultaneous analysis of proteomics, metabolomics and, transcriptomics data [26]
36.	IntegrOmics	It is a tool that can do a conjunctional analysis of variables from two different omics subfields [27]
37.	MixOmics	It is an R package tool to simultaneously analyse two or more variables from a biological dataset [28]
38.	SWNT	Single Walled Carbon Nanotubes [29]
39.	FISH	Fluorescence In-situ Hybridization; detection tool using hybridization of homologous chromosome
40.	MPSS	Massively Parallel Signature Sequencing
41.	Protein microarray	Technique to detect and identify specific proteins from a complex sample consisting of various proteins

Table 1.1: Brief information about some essential terminologies that have been used in the current article.

What do we understand by crop improvement and management? Where do we stand currently?

As the world population has been ever increasing, from time immemorial the mankind has persistently tried to alter crops. With agriculture being the primary sector of production of food as well as various economically and industrially important raw materials, and around 1.23 billion people across the world engaging in agrifood industry as their prime livelihood (according to Food and Agriculture Organization of the United Nations), such alterations become crucial to keep-up the pace with the evolving human population, their lifestyle, and needs.

Crop improvement, when simply put, refers to the process of amending the genetic makeup of the plant under investigation, for better agronomic results. There are various procedures, ranging from conventional to novel technologies, that have been employed so far to achieve the desired results. These can include:

Traditional breeding techniques such as crossing the plants with its wild relatives, or other variants, with desired traits. Even though such techniques don't need the knowledge of genes, there are high chances of failure, even after carrying out the process for multiple generations [30, 31].

Transgenic crop production which involves the incorporation of genes from other organisms into the plant under focus to achieve the desired traits, for example, bt cotton that was altered to contain Cry1Ac genes (from *Bacillus thuringiensis*) by the group of Monsanto scientists and was approved by Environmental Protection Agency in the year 1995 [32].

Genome editing using tools like CRISPR, TALEN, and Zinc Finger Nuclease can also be used to produce genetically modified crops having better desirable traits with improved agronomic value [33-35].

Another novel technology which is currently under focus is that of Nanotechnology, which has shown promising results in crop improvement programmes to combat issues regarding chemical fertilizers, herbicides, abiotic stress resistance, and hence, facilitate sustainable agricultural practices and precision farming techniques [36, 37].

Crop management, on the other hand, can be considered as an integral step in crop improvement, as it involves all the steps from sowing to taking care of the crops for better growth and yield and, storing the produce as well. In simpler terms, it refers to the practices in the real agricultural field that can help in better development of crop and higher yield. Apart from this another aspect of crop improvement would involve the lesser utilization of chemical fertilizers, herbicides, and pesticides, that also cause loss to the microbiome of the rhizosphere, by indiscriminately harming the useful micro-organisms as well [38].

Current use of omics in crop improvement and management

As we are cognizant of the fact that omics encompasses the entire process of characterization, localization, and functioning of the genome, proteins, transcriptomes, metabolic pathways in the living system, so it becomes an efficacious tool in manipulating the plant genome to achieve the desirable yield along with certain other desirable traits, such as disease resistance, biotic and abiotic stress tolerance, utilisation of cheaper alternatives of certain resources, etc. Often in order to achieve such results, modifications at cellular and molecular level become necessary, which in turn is hugely dependent upon the knowledge of genome, gene expression, protein production, etc. Although knowing about genome gives loads of solutions, knowing about the metabolic pathways, genotype- phenotype relations, and protein production among others, is of utmost importance. Thus, in order to achieve this goal, multi-omics approaches are being adopted because of their high throughput.

In modern omics approaches fields like metabolomics, phenomics, ionomics, and transcriptomics are being employed along with the already established genomic and proteomics. Such ventures, where the various avenues of omics are being amalgamated are known as multi-omics approaches. Multi-omics approaches are gaining limelight due to the awareness that, simply studying and characterization the genes would not suffice the long-term goals, rather use of panomics platform for integrating the various fields has proven to be effective due to the functional analysis of proteins and their interactions with various components, including intermediate reactions, become crucial. This is because of the fact that such reactions of the various metabolites and the proteins result into the formation of the desired characters. Also, besides modification, use of omics becomes quite essential in studying and analysing information like stress response, senescence, yield, nutritive value by deciphering the data that had been generated using the same. These analyses are carried out on the basis of the data that has been generated with respect to Epigenomes, Genomes, Glycomics, Lipidomics, Metabolomes, Microbiomics, Phenomes, Proteomes, Transcriptomes, etc.

All these data are rapidly and very efficiently generated by using the various tools and methods of omics technology, like NGS. 2D-PAGE, LC-MS, MALDI-TOF MS, Label based approaches (like Isotope-coded affinity tagging, SILAC, etc.), GC-MS, NMR, etc. As this process would involve the utilisation and integration of various subfields, it is termed as a multi-omics approach, and the data generated is known as panomics [26, 39].

The data thus generated is often submitted to the corresponding journals and databases after manuscript has been published. But it is often cumbersome to integrate the data because of lack of certain tools and studies, and also high heterogeneity of samples. Nonetheless there are a vast range of databases (e.g., NCBI, Ensembl Plants, KEGG, MetaCyc, Reactome, ProteomicsDB, PRIDE, etc.) and tools (e.g., Paintomics, 3Omics, IntegrOmics, MixOmics, etc.) available to facilitate access and integration of such data [26, 40, 41]. These data can then be compared and using additional databases various targets for genome editing, alteration of metabolic pathways, and ultimately phenotype and physiology alteration can be determined, thus facilitating use of omics in crop improvement programmes.

Limitations of using omics technology

While employing any technology it is essential to determine the limitations of such use, and like any other technology, omics technologies have their own set of limitations. Although these are not entirely centred around use of omics in agriculture, however, they are still valid arguments. The first limitation would be the low number of experiment replication in this field. Unlike fields like biochemistry, there are very low number of experiments being replicated that would aid in determining the precision of the various determined measurements. Omics are a part of computational biology and bioinformatics, which makes the use of "measurable quantities" essential in this field. Thus, replicating the experiments increases the relatability of the data. The next limitation will be that of "experimental bias". In simpler words, bias refers to the association of certain characters with a certain group of quantities compared to others. Although it is not essential for experiments to have bias while searching for various unknown and novel quantities, yet many experiments may have bias in their hypothesis. The bias in the experimental design is not easily identifiable due to its unintentional nature. However, there are misconceptions that using larger sample sizes can reduce the variations caused by bias; but this is not true. Such variations can only be solved by meticulously designing the entire experiment, sample blinding, and higher randomization of the sample. The next limitation in omics is that of data generation using small sample size. Many believe that taking a greater number of measurements can compensate for the small sample size; but it is also a misconception, as it reduces sample randomization. Also, it must be kept in mind that greater sample size takes into account the high amount of bio-variability in the sample. This also facilitates experiment replication and hence, establishes precision, accuracy, and reliability of the measurements. Additionally, there can be false positive measurements due to prior assumptions and prior probability factor.

Apart from the above mentioned ones, another significant challenge to omics technology is the method used for data generation. As is known, the various fields of omics like genomics, proteomics, transcriptomics, metabolomics, etc. deal with various kinds of data, which in turn, are generated using various techniques like, karyotyping, FISH, MALDI-TOF, MPSS, protein microarray, chromatographic techniques, etc. Each of these techniques have their own set of drawbacks; many of these techniques are labour-intensive, while many require expensive sophisticated equipment and reagents. Many have high error rates and low sensitivity, along with others not having widely accepted standard design or formats. In case of proteins, additional caution is required, as the technique used may degrade the protein structure and alter is conformation and function, thus, generating false results. Another challenge is the feasibility and compatibility of the biomarkers used in data generation [42].

In the early 2000s, when genome databases for plants- *Arabidopsis thaliana* and *Oryza sativa* were created, there was a lack of tools to facilitate the studies [43]. However, in current times there exist various tools to facilitate the process. These tools are capable of differentiating and identifying genes and metabolites, and provide a modular map describing various pathways and interactions, along with intermediates and final products, while comprehensively taking into account the fact that plants have two systems (root and shoot), with each of them having unique regulatory system for the various pathways, starting from carbon fixation to protein and fatty acid synthesis. Such analysis requires high throughput techniques to correlate morphology to physiology, and hence, predict the impacts of various factors on plant health and yield.

Current use of nanotech in crop improvement and management

With nanotechnology venturing into various fields, the use of this technique in for crop improvement and management programme was not left far behind. Owing to certain key features of nanotechnology, such as targeted delivery of chemicals, regulated chemical release, and use of specially modified chemicals (engineered nanoparticles) for precision, it has become quite popular amongst researchers to refine the conventional crop breeding techniques. Also, use of nano-fertilizers, nanopriming, nanoscale coating, nanosensors, etc. for crop improvement is emerging with great vigour. These techniques can especially be used for developing climate smart crops that are resistant to salinity, drought, and other abiotic stresses, as well as biotic stresses like insects, along with having high yield and nutritive value [37, 44-46]. This would ensure overcoming the disparities in the current global food security, besides helping countries across the globe to achieve their sustainable development goals, by promotion of sustainable agricultural practices. Another important point to be noted is that, as the population grows exponentially, there is a much more heightened depletion of resources like land, water, minerals, etc., and even though it requires great expertise, nanotechnology-based products are usually in the range of 1 to 100 nanometres, thus, utilizing lesser resources than conventional techniques [1].

Some of the most preeminent applications of nanotechnology in crop improvement are mentioned in the following table:

Sl.No.	*Name of application*	*Example*
1	Nanofertilizers	Use of CuNPs to enhance plant growth and grain yield in maize under drought stress conditions [47]
2	Nanopriming	Nanopriming Hawthorn plant seedlings using Silicon dioxide nanoparticles for inducing drought resistance [48, 49]
3	Nanoparticle based plant gene transfer	Transforming plasmid DNA into the pollen of cotton using magnetic; Transforming siRNA into tobacco leaf cells using SWNTs [50] Nanoparticle-based CRISPR-CasΦ systems are being experimented [51]
4	Nanoparticle-based chemical delivery	NPs can enter plant cells easily via cuticles, stomata or even plant cell wall pores X; Delivery of ascorbic acid into Arabidopsis thaliana leaf cells using specially modified quantum dots to improve the redox status of chloroplast [52]
5	Nanosensors	Pyroelectric nanosensors, Gravimetric nanosensors, and Smart Dust Technology- based nanosensors are some examples of nanosensors used in agriculture [53]

Table 1.2: lists certain applications of nanotechnology in crop improvement and some examples of their successful implementation that would prove to be a blueprint for future prospects.

Even though there are various techniques involved in crop improvement and management programmes, yet making alterations at the genetic level remains an efficient and preferred technique to achieve long- term and efficient goal. Thus, genetic engineering becomes an indispensable tool. Hence, coupling this tool with nanotechnology enhances its efficiency manifolds. As is evident from various texts, nanotechnology- based gene transfer is far more advantageous. This is supported by some of the salient features of nanoparticles (or ENPs) such as precise targeting of molecules that can facilitate proper insertion of the gene of interest into the desired position in the genome, and also the fact that gene of interest carried by ENPs are much more protected from degradation. All these facts give nanotechnology-based gene transfer an upper hand [52, 54-57].

Limitations of using nanotechnology in crop improvement and management

Nanotechnology is known to produce products having novel characteristics by altering materials at the level of atoms and molecules. These ENMs are used in the form of nanofertilizers, nanopesticides, nanoherbicides, nanosensors, etc., and have an edge over their conventional counter-parts, like smart and precise delivery of genes and chemicals. However, as with any other technology, use of ENMs have an array of uncertainties as well. The first and foremost drawback would be the limited number of studies on the toxicity of ENMs. There exist uncertainties regarding the degradation of NPs (Nanopartticles) in the environment. NP-based chemicals are known to cause far less environmental implications than their conventional counterparts, but also, we have limited knowledge about their accumulation in living systems. Due to their minute size, it would be easy for NPs to enter non-targeted living systems as well as non-targeted tissues in the target body as well. It is to be determined to what extent such unwanted interactions can cause severe implications. It is to be noted that, silver NPs can be lethal to earthworms, which are known for their significant beneficial activities in agricultural fields. Also, as with certain herbicides, the nanoherbicides also have the potential to kill useful crops, but these results are yet to be proven.

Additionally, these ENMs have the capability of crossing the blood-brain barrier upon consumption. Also, these ENMs can be dermally absorbed posing a threat to the consumer's health. It is also known that exceeding the optimal level of nanofertilizer use can reduce the yield, instead of enhancing it. Thus, there are various unknown implications of NPs on health of both plant and the consumer, and also on environment. Ecotoxicity tests are thus of importance to expanding the benefits of using nanotechnology [58, 59].

In case of gene delivery and genome editing driven by nanotechnology, the most crucial obstacle is crossing the cell wall in the plants. The cell wall acts as a rigid and protective barrier to facilitating such operations [51]. Also, use of sensors at nano-scale are seen to be less sensitive and cause disruption in proper functioning. Limitations were witnessed in the performance of certain optical nanosensors due to their small size [60, 61].

Thus, the ecotoxicity test of NPs are a major limitation in their efficient use. However, this is also due other extraneous factors like lack of awareness amongst the users. The common farmer might not be readily welcoming towards the use of nanotechnology-based products, like nanofertilizers, as a new alternative. Another misconception among farmers is that, the use of higher quantities of fertilizers will keep on exponentially increasing the yield, but this is just a misconception, as there exist threshold limits. And in the case of nanofertilizers, more than optimal levels can be degenerative in their function. Thus, proper instructions are needed for their application; for the common farmer it is often a disbelief that such low quantities of fertilizers can increase yield. Hence, many opt for combined use of nanofertilizers and their conventional counterparts, therefore, nullifying the ultimate goal and benefit of NP use.

Nano-omics: Integrating Omics and Nanotechnology

As is evident from its name, the amalgamation of nanotechnology-based tools and omics data come at the core of Nano-omics. Currently, it is at its infancy stage, yet it has gained tremendous attention owing to its features, that combine the benefits of nanotechnology over conventional techniques with the rapid and efficient data generation, comparison, and deduction benefits of omics technology, as it uses tools of bioinformatics. All these facts become a key in making it a hard to overlook tool in combating issues of sustainable and precision farming. For example, if we consider the current scenario, where there is a predominant lack of certain resources, further worsened by human activities and climate change (e.g., degrading ground water level and lack of proper rainfall at certain locations, can deplete water available for irrigation) then such locations require crops that are highly resistant to drought stress, but such crop variants might not be available naturally for the agriculturally important plant species. Thus, to make agriculture feasible in such circumstances, it becomes necessary to device strategies to improve the required crop variant. Such modifications, in turn would require generation of data or acquisition of existing data regarding the various molecular aspects, which could be done using various omics technologies followed by panomics integration to understand the underlying mechanisms of the impact of drought stress in the crop. On the other hand, studying the panomics of drought resistance in certain underutilized relatives or other species would serve as a solution, since thus would enable us to understand what are the underlying genes that give certain plant varieties such advantages in the form of stress resistance. This understanding would help us to understand the genotype-phenotype interrelationship, thus giving us a concrete base to start with the alteration of the genome, phenotype, and metabolic pathways, etc. of our desired plant variety. Now, ordinarily, the preferred way would be the use of conventional genetic engineering and recombinant DNA technology, but for much more efficiency and precise targeting, nanotechnology can be employed, adding to this targeting of molecules coated with NPs reduce their chances of being degraded and increase their protection during the process of transfer. Thus, in such was the field of nano-omics can efficiently suffice the procedures required in crop improvement programme.

Though not much work has been carried out in this amalgamated field, especially with respect to crop improvement and management, it is very much expected to be a trailblazer in fulfilling the goals of precision farming and sustainable agricultural practices. As mentioned previously, if nano-omics techniques can be performed successfully, then it would alleviate the stress resistance and adaptive features of several commercially important and nutritional essential crops by enabling them to combat stress such as, increased salinity, reduced water, and high temperatures apart from biotic stresses like diseases pathogens, etc. [54-56].

Table 1.2 highlights certain such techniques and examples of their successful implementations that can prove to be a blueprint for future research in this nascent field.

What is the need to develop such integrated fields like nano-omics?

The integration of such highly sophisticated fields like omics and nanotechnology, which have themselves helped in overcoming the shortcomings of conventional techniques, would facilitate much more efficient crop improvement owing to the utilisation of both of their salient features. As we know that omics technologies and amalgamation of all of its subfields would result in completely deciphering the underlying causes of plants response to various stressful as well as favourable conditions, this would be much easily utilized due to the availability of panomics tools that are already available. But nonetheless, it would not be realized fully in practice until and unless advanced techniques like nanopriming, nanofertilizers, nanosensors, etc., are used along with it. Thus, to efficiently and sustainably utilize the available resources such integrations are much needed.

Thinking beyond the scientific arena

When discussing technologies that are aimed at solving socio-economic issues like food security and sustainability, it is essential that we talk about the associated ethical and social issues. The foremost issue at hand is the use of genetically modified (GM) crops even when it is nanotechnology driven. With various communities being against the consumption of GM crops, nanotechnology-based genome editing is not likely to be easily employed. Various countries across the world, especially the countries of the European Union, have shown resistance to widespread use of GM crops; it is due to the various uncertainties, like- if there can be geneflow from one species to another, if such transformed genes get incorporated into the consumer's system or if it has any oncogenic or immunogenic impacts, etc. This is accompanied by the fact that many communities consider GM crops to be against their religious beliefs. Thus, it may not be an entirely different world for nanotechnology-based genome editing.

The efficient use of NPs also requires extensive toxicity and ecotoxicity tests to estimate their implications on consumer health and environment. The degradability of NPs in the environment still remains a question. The reports of ENMs entering the body of the consumer are an issue that needs to be addressed before promoting its widespread use. Along with this, there are issues of lack awareness regarding nanotechnology-based products, causing disruptions in their widespread agronomical use.

Current challenges and Way forward

Although individually both nanotechnology and omics technology are quite well established, yet Nano- omics is in a very nascent phase, especially with respect to agriculture and plant breeding since relatively not much work has been done in this paradigm. This can be reasoned out by highlighting that not every species across the world has been completely documented in omics databases. Also, the search for certain beneficial genes continues that can help alleviate certain stress conditions in the required plant species that would lead to desired results, such as induce resistance to entire set of pathogens affecting that plant. Apart from this there are still many unanswered questions regarding the environmental safety and toxicity of NPs [62] and also a lack of dedicated and comprehensive databases for various agriculturally valuable crop species. This is further accompanied by uncertainties resulting from unforeseen interactions at molecular levels, for which much research still needed. Even though there are many dedicated and comprehensive databases already available for certain plant species, many milestones are yet to be achieved. Apart from this, there always remains an issue that can never be overlooked, due to its ethical nature. As we know, there are various communities across the world that prohibit the use and consumption of genetically modified crops and crops that have not been grown according to conventional agricultural practices. This creates a consumption and demand gap which when not addressed can lead to constraints in achieving a stable economy, which is one of the ultimate goals of sustainability. Such circumstances are accompanied by activists who advocate against altering the nature. The key to combat such circumstances would include:

- Overcoming the research gap,
- Making much of the data available in databases much more comprehensive,
- Construction of comprehensive and dedicated databases for agriculturally valuable crop species and their wild and underutilized relatives, and the making these databases inclusive in nature by integrating data from various omics sub-disciplines to get a comprehensive and quantitative information regarding molecular level interactions that impact the phenotype and physiology,
- Efficient storage and sharing of all such deciphered data, Improvement and simplification of nanotechnology-based tools, and a better understanding of nanotoxicity and impacts of NPs on environment [63].
- Lastly, spreading awareness regarding such improved crop varieties across the population to induce their acceptance as consumables.

Conclusion

Venturing into the third decade of 21st century, the world has seen various landmark events involving a pandemic, the great population boom, and also threats to food security due to various conflicts. But alongside, the humanity has also witnessed much progress in science and technology which can bring about revolutionary amendments to the way the world lives. One such avenues is that of Nano-omics which combines two very sophisticated disciplines of modern science and technology. With its lucrative features, it has the potential to become the most preferred tool for plant genetic engineers and breeders.

According to the various figures published by the United Nations, about 828 million people were left undernourished and 349 million people kept facing food security threats, in the year 2022, which is very alarming and calls for immediate resolution. Such conditions have long been faced by the world, especially by the developing countries, with a lack of resources. This situation can be tackled by sustainable development measures, which would undoubtedly include precision farming and sustainable agricultural practices to enhance the resource management. These goals can be sufficed by the involvement of multidimensional approaches like the one that has been discussed in the above article. Though much research gap has to be fathomed yet such approaches would ensure a better future.

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Conflict of interest

The authors declares no conflict of interest.

References

1. Whatmore RW. “Nanotechnology—what is it? Should we be worried?”. Occup. Med 56 (2006): 295-299.
2. Fischer HC and Chan WC. “Nanotoxicity: the growing need for in vivo study”. Curr. Opin. Biotechnol 18 (2007): 565-571.
3. Lockhart DJ and Winzeler EA. “Genomics, gene expression and DNA arrays”. Nature 405 (2000): 827-836.

4. McArdle AJ and Menikou S. "What is proteomics?". Arch. Dis. Child. - Educ. Pract. Ed 106 (2021): 178-181.
5. Systematic Cell Phenotyping. in Phenomics (ed. Hancock, J. M.). CRC Press (2016): 96-120.
6. Lowe R., et al. "Transcriptomics technologies". PLOS Comput. Biol 13 (2017): e1005457.
7. Alseekh S and Fernie AR. "Metabolomics 20 years on: what have we learned and what hurdles remain?". Plant J 94 (2018): 933-942.
8. Roessner U and Bowne J. "What is metabolomics all about?". BioTechniques 46 (2009): 363-365.
9. Baxter I. "Ionomics: The functional genomics of elements". Brief. Funct. Genomics 9 (2010): 149-156.
10. Wenk MR. "Lipidomics: New Tools and Applications". Cell 143 (2010): 888-895.
11. Van Meer G. "Cellular lipidomics". EMBO J 24 (2005): 3159-3165.
12. Das AJ. "Microbiomics and cloud-based analytics advance sustainable soil management". Front. Biosci 26 (2021): 478-495.
13. Cummings RD and Pierce JM. "The Challenge and Promise of Glycomics". Chem. Biol 21 (2014): 1-15.
14. Bradbury J. "Human Epigenome Project—Up and Running". PLoS Biol 1 (2003): e82.
15. Becker S and Boch J. "TALE and TALEN genome editing technologies". Gene Genome Ed 2 (2021): 100007.
16. Carroll D. "Genome Engineering with Zinc-Finger Nucleases". Genetics 188 (2011): 773-782.
17. Sandhu C, Qureshi A and Emili A. "Panomics for Precision Medicine". Trends Mol. Med 24 (2018): 85-101.
18. Behjati S and Tarpey PS. "What is next generation sequencing?". Arch. Dis. Child. - Educ. Pract. Ed 98 (2013): 236-238.
19. Chen X., et al. "Quantitative proteomics using SILAC: Principles, applications, and developments". Proteomics 15 (2015): 3175-3192.
20. Gygi SP., et al. "Quantitative analysis of complex protein mixtures using isotope-coded affinity tags". Nat. Biotechnol 17 (1999): 994-999.
21. 'In Silico' Simulation of Biological Processes. John Wiley, New York (2002).
22. Karp PD. "The MetaCyc Database". Nucleic Acids Res 30 (2002): 59-61.
23. Croft D., et al. "Reactome: a database of reactions, pathways and biological processes". Nucleic Acids Res 39 (2011): D691-D697.
24. Schmidt T., et al. "ProteomicsDB". Nucleic Acids Res 46 (2018): D1271-D1281.
25. Garcia-Alcalde, F., et al. "Paintomics: a web based tool for the joint visualization of transcriptomics and metabolomics data". Bioinformatics 27 (2011): 137-139.
26. Misra BB., et al. "Integrated omics: tools, advances and future approaches". J. Mol. Endocrinol 62 (2019): R21-R45.
27. Le Cao K-A, Gonzalez I and Dejean S. "IntegrOmics: an R package to unravel relationships between two omics datasets". Bioinformatics 25 (2009): 2855-2856.
28. Rohart F., et al. "mixOmics: An R package for 'omics feature selection and multiple data integration". PLOS Comput. Biol 13 (2017): e1005752.
29. Monthioux M. "Filling single-wall carbon nanotubes". Carbon 40 (2002): 1809-1823.
30. Shimelis H and Laing M. "Timelines in conventional crop improvement: pre-breeding and breeding procedures".
31. Environment, Climate, Plant and Vegetation Growth. Springer International Publishing, Cham (2020).
32. Abbas MST. "Genetically engineered (modified) crops (Bacillus thuringiensis crops) and the world controversy on their safety". Egypt. J. Biol. Pest Control 28 (2018): 52.
33. Zhang Y., et al. "The emerging and uncultivated potential of CRISPR technology in plant science". Nat. Plants 5 (2019): 778-794.
34. Weinthal D., et al. "Genome editing in plant cells by zinc finger nucleases". Trends Plant Sci 15 (2010): 308-321.
35. Malzahn A, Lowder L and Qi Y. "Plant genome editing with TALEN and CRISPR". Cell Biosci 7 (2017): 21.
36. Mousavi SR and Rezaei M. Nanotechnology in Agriculture and Food Production (2011).
37. Pramanik P., et al. "Application of Nanotechnology in Agriculture". in Environmental Nanotechnology Volume 4 (eds. Dasgupta, N., Ranjan, S. & Lichtfouse, E.) (Springer International Publishing, Cham 32 (2020): 317-348.
38. Gupta A., et al. "Linking Soil Microbial Diversity to Modern Agriculture Practices: A Review". Int. J. Environ. Res. Public. Health 19 (2022): 3141.

39. Yang Y., et al. "Applications of Multi-Omics Technologies for Crop Improvement". Front. Plant Sci 12 (2021): 563953.
40. Scossa F, Alseekh S and Fernie AR. "Integrating multi-omics data for crop improvement". J. Plant Physiol 257 (2021): 153352.
41. Ambrosino L., et al. "Bioinformatics Resources for Plant Abiotic Stress Responses: State of the Art and Opportunities in the Fast Evolving - Omics Era". Plants 9 (2020): 591.
42. Lay JO., et al. Problems with the "omics". TrAC Trends Anal. Chem 25 (2006): 1046-1056.
43. Omodele I. "Omics Technologies in Unraveling Plant Stress Responses; Using Sorghum as a Model Crop, How Far Have We Gone?". Vegetos 31 (2018).
44. War JM., et al. "Role of Nanotechnology in Crop Improvement". in Nanobiotechnology in Agriculture (eds. Hakeem, K. R. & Pirzadah, T. B.). Springer International Publishing, Cham (2020): 63-97.
45. Almutairi ZM. Effect of nano-silicon application on the expression of salt tolerance genes in germinating tomato (Solanum lycopersicum L.) seedlings under salt stress.
46. B S. Nanotechnology in Agriculture. J. Nanomedicine Nanotechnol 02 (2011).
47. Ha C. Copper nanoparticle application enhances plant growth and grain yield in maize under drought stress conditions (2020).
48. Nanopriming Approach to Sustainable Agriculture: (IGI Global, 2023).
49. Peyman Ashkavand., et al. Effect of SiO2 nanoparticles on drought resistance in hawthorn seedlings Effect of SiO2 nanoparticles on drought resistance in hawthorn seedlings.
50. Lv Z., et al. "Nanoparticle-mediated gene transformation strategies for plant genetic engineering". Plant J 104 (2020): 880-891.
51. Wu H and Li Z. "Recent advances in nano-enabled agriculture for improving plant performance". Crop J 10 (2022): 1-12.
52. Santana I., et al. "Targeted delivery of nanomaterials with chemical cargoes in plants enabled by a biorecognition motif". Nat. Commun 11 (2020): 2045.
53. Rameshaiah DGN and Shabnam S. Nano Fertilizers and Nano Sensors - An Attempt for Developing Smart Agriculture 3 (2015).
54. Begum SLR and Jayawardana NU. "A Review of Nanotechnology as a Novel Method of Gene Transfer in Plants". J. Agric. Sci. - Sri Lanka 16 (2021): 300-316.
55. Ohadi Rafsanjani MS., et al. "Application of Novel Nanotechnology Strategies in Plant Biotransformation: A Contemporary Overview". Recent Pat. Biotechnol 6 (2012): 69-79.
56. Niazian M., et al. "Perspectives on new opportunities for nano-enabled strategies for gene delivery to plants using nanoporous materials". Planta 254 (2021): 83.
57. Ahmar S., et al. "Advantage of Nanotechnology-Based Genome Editing System and Its Application in Crop Improvement". Front. Plant Sci 12 (2021): 663849.
58. Forini MML., et al. "Nano-enabled weed management in agriculture: From strategic design to enhanced herbicidal activity". Plant Nano Biol 1 (2022): 100008.
59. Vijayakumar MD., et al. "Evolution and Recent Scenario of Nanotechnology in Agriculture and Food Industries". J. Nanomater (2022): 1-17.
60. Dahlin AB. "Size Matters: Problems and Advantages Associated with Highly Miniaturized Sensors". Sensors 12 (2012): 3018-3036.
61. Nair PR and Alam MA. "Performance limits of nanobiosensors". Appl. Phys. Lett 88 (2006): 233120.
62. Colvin VL. "The potential environmental impact of engineered nanomaterials". Nat. Biotechnol 21 (2003): 1166-1170.
63. Surette MC., et al. "What is "Environmentally Relevant"? A framework to advance research on the environmental fate and effects of engineered nanomaterials". Environ. Sci. Nano 8 (2021): 2414-2429.

Volume 7 Issue 1 July 2024