Journal of Phytonanotechnology and Pharmaceutical Sciences 1(2): 17-20, 2021

http://jpps.ukaazpublications.com

DOI: http://dx.doi.org/10.21276/jpps.2021.1.2.3

Journal of Phytonanotechnology and Pharmaceutical Sciences

Review Article : Open Access

Crop improvement *via* nanotechnology: An overview

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Article Info

Article history
Received 7 April 2021
Revised 9 May 2021
Accepted 10 May 2021
Published Online 30 June 2021

Keywords
Nanotechnology
Smart sensors
Crop improvement
Speed breeding
Gene editing

Abstract

Nanomaterials with their versatile properties are of interest in plant science as vehicles biomolecules in plants, genetic engineering and, thereby enhance crop productivity. Speed editing protocols by incorporating nanomaterial is under progress. Nanotechnology (NT) assisted crop breeding is a new strategy and it can be potentially extended to other plants. It is simple with quick method for editing plant genomes, in addition to cost effectiveness. It takes a pivotal role in vivid crop breeding plans to enhance the yield and quality enhancement. It can be potentially extended to other plants, hence, has greater applications to be exploited in a big way.

1. Introduction

Nanomaterials have unique physicochemical properties and hence, the field of nanotechnology is gaining an increased interest in plant science, with potential for the application of nanomaterials as vehicles biomolecules in plants, and thereby enhance crop productivity (Khan *et al*., 2017), and crop improvement (War *et al*., 2020).

As per ASTM standards, nanomaterials abbreviated as NMs are the natural material or manufactured ones with size of 1 and 100 nm (ASTM, 2012). They have high surface-to-volume ratio, having chemical and physical properties as compared to their bulk counterparts, suiting them to various fields (Roduner, 2006; Jeevanandam *et al*., 2018). Recent advances have certain applications in plant growth, productivity enhancement as per Wang *et al*. (2016). In view of costly and hazardous traditional chemicals, polymeric nanomaterials due to their biocompatibility, synthesis at low-cost and prompt response ability to external stimuli (Baskar *et al*., 2018) made them attentive. Core/Shell NPs and choice of the shell of the NPs depends on the kind of application (Ghosh Chaudhuri and Paria, 2012). Earlier reviewers reported on biocompatibility of the NPs (Nath *et al*., 2008), nanostructured shell (Torney *et al*., 2007), nanogels (Molina *et al*., 2015) and their classification (Molina *et al*., 2015) as well. NT has smart applications in plant sciences and agricultural science, but to be exploited in a big way (Wang *et al*., 2016). Keeping the above in view, an over view is attempted to update the present happenings in respect of application of nanotechnology in crop improvement.

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2. Applications

2.1 Applications in biosensors

NMs act as "sensing materials" and had practical applications in crop biotechnology (Chaudhry *et al*., 2018). Different categories of nanosensor types such as plasmonic nanosensors, fluorescence resonance energy transfer (FRET) based nanosensors, carbon-based electrochemical nanosensors, nanowire nanosensors and antibody nanosensors were verified for their applications in biotechnology. Application of nanosensors in plants is at nascent stage (Rai *et al*., 2012). Their use for detection and quantification of plant metabolic flux, viral and fungal pathogens (Table 1) is proposed. In onion, fabrication of a fluorometric optical onion membrane-based sensor for detection of sucrose based on the synthesis of invertase-nanogold clusters embedded in plant membranes (Bagal-Kestwal *et al*., 2015) is reported.

2.2 Application of nanomaterial in plant genetic engineering

Silicon Carbide-Mediated transformation used to deliver DNA in different calli of tobacco, maize, rice, soybean and cotton (Asad and Arsh, 2012; Lau *et al*., 2017) and helped to overcome the cell wall barriers in old plants (Table 2).

The dsRNA of different plant viruses can be loaded on non-toxic, degradable, layered double hydroxide. The dsRNAs and/or their RNA breakdown products provide protection against the Cauliflower Mosaic Virus in sprayed leaves. This provides a proof of concept for species-independent and p assive, without transgene integration into plant cells.

Table 1: Some nanomaterial used as biosensors in plant experiments and their effects

Nanomaterial	Function	Plant used for the experiment	Reference
Single-walled carbon nanotubes	Near-infrared fluorescence monitoring of nitric oxide	*A. thaliana*	Giraldo *et al*., 2014, 2019
FRET probes with polystyrene NPs	Phytoalexins quantification and recognition		Dumbrepatil *et al.*, 2010
NM biosensors	Microbes rapid detection, precise quantification	Plants	Duhan *et al.*, 2017
Fluorescent silica NPs along with antibody	Bacterial spot disease	Solanaceae plants	Yao *et al*., 2009
DNA biochemical labels on carbon electrodes	Detection of *Pseudomonas syringae*	*A. thaliana*	Lau *et al*., 2017.
Au NPs	Diagnosis of the phytoplasma of flavescence dorée disease	Grapevine	Firrao *et al*., 2005.
Various smart nanosensors	Mycotoxin detection	Oat, Corn, Barley and Wheat	Lattanzio and Nivarlet, 2017

Table 2: Some nanomaterial used in plant genetic engineering

Nonmaterial	Function	Plant used for the experiment	Nature of experiment	Reference
Clay nanosheets or bioclay	Mode of delivery of genetic material	Tobacco	Biotechnology	Mitter *et al*., 2017
Mesoporous silica nanoparticles (MSNs)	Delivery of Cre recombinase carrying *loxP* sites integrated into chromosomal DNA	Maize	Genome editing	Valenstein *et al*., 2013
Carbon nanotubes	DNA delivery	Cotton	Genetic transformation	Zhao *et al*., 2017
Carbon nanotubes	Deliver DNA, siRNA	*N.benthamiana*, wheat, cotton leaves	DNA delivery	Demirer *et al*., 2018

Table 3: Use of engineered nonmaterial's in plant experiments

Form of the nanoparticle	Reported function	Crop
Gold	Reductions in biomass and transpiration rates	*Cucurbita pepo*
Gold	Reduced biomass and transpiration	Pumpkin
Cadmium	Root growth	Carrot, cucumber, tomato
TiO_2	Increase in nitrate reeducates.	Soybean
Graphene	The root hair growth decreased.	Red spinach and cabbage
Graphene	Modifications in gene expression	Fruits, leaves, and roots
MWCNTs	Creation of new pores and water uptake	Tomato seedlings
MWCNTs	Seed germination and root elongation	Zucchini species
SWCNTs	Increased its widespread, dispensability, and water column stability	-
Carbon nanotubes	Improve root growth	Cucumbers, onions
Carbon nanotubes	Diminish root growth	Tomato plants
Fullerol	Apoplectic mode of transport in the plant tissues	-

2.3 Use of engineered nanomaterials

Engineered nanomaterials research and development, in agricultural applications, probably facilitated and framed the next stage of development of genetically modified crops (GMCs), animal production input, biocides, and precision farming system.

Various engineered nanoparticles such as fullerene, fullerol small size and hydrophobicity properties, carbon nanotubes (single or multiple layers of carbons established in a cylinder), gold (Au), TiO_2 (small size (<5 nm), MWCNTs (Multiwall carbon nanotubes) with 1 mm long and 20 nm in diameter and graphene (two dimensional crystalline allotrope of carbon) have applications in crop improvement (Table 3).

2.4 Application of nanobiotechnology for crop improvement

CRISPR was used under speed editing strategies by incorporating NMs to combine with speed breeding. Nanotechnology is useful to their double-stranded RNA efficacy for plant improvement (Hofmann *et al.*, 2020). NMs used for grafting can be useful to deliver molecules to GE (Wang *et al.*, 2019). Demirer *et al.* (2019) devised a tool for the species-independent, targeted, and passive delivery of genetic materials into plant cells without transgene integration. Efficient DNA delivery and strong transient protein expression were achieved in *Eruca sativa* and *T. aestivum* leaves and protoplasts. Demirer *et al.* (2019) demonstrated a second NP-based strategy in which low interfering RNA is delivered to mature *Nicotiana benthamiana* leaves to silence a gene. NPs can potentially deliver gene-editing cargos to any plant cells and meristematic cells (Sanzari *et al.*, 2019; Wang *et al.*, 2020).

The delivery of GE reagents *via* NPs into meristematic cells can potentially generate chimerically edited plants. The Cas9/gRNAs produced *via* this method successfully edited target genes (Doyle *et al.*, 2019).

Table 4: Steps in speed breeding

Step 1	Selection of candidate(s)
Step 2	Delivery of genetic materials using a different type of nanotubes
Step 3	T_0-generation of seed

The speed breeding methods (Table 4) improves the rapid growth of various agricultural crops such as oat, various *Brassica* species, chickpea, pea and grass pea.

3. Conclusion

Nanotechnology based crop breeding is a new strategy. It is simple with quick method for editing plant genomes, in addition to cost effectiveness. It takes a pivotal role in vivid crop breeding plans to enhance the yield and quality enhancement. It can be potentially extended to other plants.

Funding

The present research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors acknowledge the research workers in the area of nanotechnology, who are applying it for the crop improvement

Conflicts of interest

The authors declare that there are no conflicts of interest relevant to this article

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Citation **Saidaiah Pidigam and Geetha Amarapalli (2021). Crop improvement *via* nanotechnology: An overview. J. Phytonanotech. Pharmaceut. Sci., 1(2):17-20. http://dx.doi.org/10.21276/jpps.2021.1.2.3**