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Molecular Plant Nutrition in the Era of Nanotechnology: A Short Communication

Sarwat M. Youssef [#], Mohamed A. Koriem and Hassan R. El-Ramady *
Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University, 33516Kafr El-Sheikh, Egypt
[#] Deceased

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PLANT nutrition is an important branch of plant biology, which deals with different nutrients, and their uptake by cultivated plants as well as their biochemical functions in plants. This science is also involving the production of safe and healthy food depending on the famous rule "*the right 4R Nutrient Stewardship to improve nutrient use efficiency*". Several methodologies have been used in plant nutrition research including pot, hydroponic or soilless, micro-farm and field studies, as well as *in vitro* or plant tissue culture. These studies have focused on many aspects (i.e., physiological, biochemical, anatomical and molecular scales). The molecular plant nutrition has become a crucial issue in different case studies concerning agricultural production particularly under stressful conditions. Molecular plant nutrition research has gained a new dimension in the era of nanotechnology especially under plant nano-nutrition. Several open questions still need to be answered such as what are the possible applications of nanotechnology in molecular plant nutrition? To what extent nano-nutrients can be used in molecular plant nutrition studies and which criteria should be followed in this usage?

Keywords: Nutrients, Nanoparticles, Nano-nutrients, Genetic level, Nano-nutrition.

1. Molecular plant nutrition

The agricultural production from crops depends on several factors including the nutritive elements in soil (Table 1). Yet the available forms of these nutrients are almost not enough to satisfy plant needs for proper plant growth and also exhibit seasonal variations (El-Ramady et al. 2014a). Generally, nutritive elements are taken up selectively by plant roots *via* "intrinsic transmembrane transporter proteins", which are divided into two classes: ion channels in plasma membrane (Mitra 2015) and ion transporters or carriers. These carriers are energetic 'vectoral' enzymes which can bind specifically with ions and facilitate their movement across cell membrane against the electrochemical gradient (not ion channels). This process requires energy from the hydrolysis of ATP molecules (Dubyak 2004).

Plant nutrients can be taken under genetic control like nitrogen in form of NO_3^- or NH_4^+. Generally, there are high-affinity transporters, for the influx of low ion concentrations, and the low- affinity transporters which are mainly used for transportation of high concentrations of ion across plasma membrane (Table 2). Many of these transporters have been characterized and

*Corresponding author e-mail: hassan.elramady@agr.kfs.edu.eg
Authors' emails: koriemmohamed@yahoo.com
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their modes of action have become well known (Mitra 2015).

During the last three decades, intensive researches have been carried out globally for more discoveries and explanations about the uptake of nutrient by cultivated plants at the molecular level, which has been generated a lot of information. This information was resulted primarily from using modern technology, which was developed in different disciplines like biotechnology, bioinformatics, -omics and modern computation facilities (Mitra 2015). The uptake of different nutrients depends on a large number of metabolic enzymes, which can up- and down-regulate these nutrients as a response to the deficiency of plant nutrients. Therefore, many plant growth regulators, amino acids, secondary metabolites and the nutrients themselves are involved in the repression or induction of transporter-encoding genes as well as post- transcriptional modification of transporter proteins (Mitra 2015). Table 2 presents list of the common transporters of main and some beneficial nutrients.

TABLE 1. Different fields of plant nutritionhave been used in the study during the last decades

Item	Details about the fields of plant nutrition (Reference)
The main books/articles in the field of plant nutrition	
	New remarks of a chemical nature on the choice of mature culture media and on the way of formulating synthetic media (Berthelot 1934)
	Serial culture of plant tissues on artificial media (Nobécourt 1937)
	Soilless growth of plants (Eastwood 1947)
	Diagnostic criteria for plants and soils (Chapman 1972)
	Diagnosis of nutrient requirement by plants (Bergmann and Cumakov 1977)
	Plant nutrition: an introduction to current concepts (Glass 1989)
	Mineral nutrition of higher plants (Marschner 1995)
	Growth and mineral nutrition of field crops (Fageria et al. 1997)
	Plant nutrition research and its priorities in sustainable ways (Cakmak 2001)
	Nutrient use efficiency in plants (Baligar et al. 2001)
	Principles of plant nutrition (Mengel et al. 2001)
	Mineral nutrition of plants: principles & perspectives (Epstein & Bloom 2005)
	Plant nutrition for food security (Roy et al. 2006)
	Plant nutrition of greenhouse crops (Sonneveld and Voogt 2009)
	The use of nutrients in crop plants (Fageria 2009)
	Trace elements and their contents in soils and plants (Kabata-Pendias 2011)
	Plant nutrition and Soil fertility manual (Jones 2012)
	Marschner's Mineral Nutrition of Higher Plants (Marschner 2012)
	Regulation of Nutrient Uptake by Plants Molecular Approach (Mitra 2015)
	Handbook of Plant Nutrition (Barker and Pilbeam 2015)
The main topic-studiesin plant nutrition	
Hydroponics	Gericke (1937); Jones (1982, 2005); Vanipriya et al. (2021)
Pot experiments	Trolldenier (1987); Madsen and Crook (2021)
Plant tissue culture	Gautheret (1939); Murashige and Skoog (1962); Tarrahi et al. (2021)
Field experiments	Collis-George and Davey (1960); Gomez (1972); Fageria (2006)
Greenhouse studies	Sonneveld and Voogt (2009); Incrocci et al. (2020)
Isotope studies	Pfahler et al. (2017); Wang et al. (2021)
Controlled research	Soil fertility and plant nutrition research under controlled conditions (Fageria 2005)
Micro-farm studies	El-Ramady et al. (2014a, b), (2016)
Soilless culture	Gericke (1940); Steiner (1985); Raviv and Lieth (2008); Massa et al. (2020)
Molecular studies	Mitra (2015); Tian et al. (2021)

TABLE 2. List of the transporters of some nutrients that are common in molecular plant nutrition

Nutrient	Common transporters of nutrients	Reference
Nitrogen, N	NRT1 and NRT2 for nitrate	Crawford and Glass (1998)
Phosphorus, P	Pi-transports including PHT1, PHT2, PHT3, PHT4	Bieleski (1973)
Potassium, K	AKT1, KAT1 and KAT2	Gierth and Mäser (2007)
Calcium, Ca	Ca/H^+ antiporters, P-type Ca-ATPases	De Silva et al. (1998)
Magnesium, Mg	CorA and CorA homologues	Niegowski and Eshaghi (2007)
Sulphur, S	Sultr (sulphate uptake pathway)	Shinmachi et al. (2010)
Boron, B	NIP 5;1 – NIP 6;1 – BOR1 (first boron transporter)	Takano et al. (2006)
Chloride, Cl^-	AtCLC, a-g (for *Arabidopsis*);OsCLC, 1–7 (for rice)	de Angeli et al. (2009)
Cobalt, Co	CDFs: Cation Diffusion Facilitators Family	Hall and Williams (2003)
Copper, Cu	COPT family, P_{1B}-ATPases, ZIP family, YSL transporters	Milner et al. (2013), Yruela (2009), Puig et al. (2007)
Iron, Fe	AtIRT1(at high affinity), AtIRT2 (at low affinity)	Mitra et al. (2009)
Manganese, Mn	ZIP7, AtCAX1, and AtCAX2	Cailliatte et al. (2010)
Molybdenum, Mo	Sultr5;2 (MOT1) sulphate uptake pathway	Shinmachi et al. (2010)
Nickel, Ni	AtIRT1 from ZIP family, YSL transporters, CAX	Eide et al. (1996)
Selenium, Se	Selenate (SULTR1;1 and SULTR1;2), selenite by phosphate transporters	Schiavon and Pilon-Smits (2017), White (2018)
Silicon, Si	Si-transporters like LSi1, LSi2and LSi6	Ma et al. (2006), Yamaji et al. (2012)
Sodium, Na	HKT (high-affinity K^+ transporters) like AtHKT1;1	Mäser et al. (2002)
Zinc, Zn	MTPs, P-Type ATPase(HMAs), ZIP family	Kramer (2005); Mapodzeke et al. (2021)

Abbreviations: CorA: Cobalt-Resistant Phenotype of Bacterial Mutants; **AtIRT1:** Fe-regulated transporter1; **MTPs:** metal transporter proteins; **HMAs:** The heavy metal ATPases and belong to P_{1B} subfamily of P-type ATPase superfamily; **COPT**: Copper Transporter Proteins; **NIP 5;1**: Nodulin-26-Like Intrinsic Proteins; **YSL**: Yellow stripe-like transporters; **CAX** Family (Cation/H^+ Antiporters); **SULTR:** sulphate transporters

Source: According to Mitra (2015)

Day by day, a great concern on the molecular plant nutrition has been shown in different regions worldwide like in Germany, which has Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), at Gatersleben as a famous group of molecular plant nutrition (Fig. 1). The significance of molecular plant nutrition may back to the amazing progress in the field of methodology, which could support researchers on the genetical scale beside the biochemical or/ and physiological levels.

2. Nanotechnology for molecular plant nutrition

It is well known that, nanomaterials (NMs) have received a great concern in the last decades due to their unique properties and useful applications in several fields leading to mass production of these materials (Tarrahi et al. 2021). Based on the extensive NM-applications in agriculture and medicine, several plant-NM interactions could be expected, which need a comprehensive understanding of bio-nano interactions (Tarrahi et al. 2021). Many applications of nanotechnology in the field of molecular plant nutrition could be identified such as biocontrol delivery system for controlling some plant diseases (Djaya et al. 2019), genetic transformation in plants using nanomaterials for smart delivery of biomolecules (Banerjee et al. 2019; Sanzari et al. 2019), nano application for therapeutic and diagnostic systems (Bassous and Webster 2020), gene delivery to plants using nano-enabled strategies (Chandrasekaran et al. 2020; Niazian et al. 2021), and nanotoxicological studies under plant tissue culture conditions (Tarrahi et al. 2021).

Therefore, this is a series of call for submitting original articles, review or mini-review articles, comments and notes to EBSS Journal, including the integration of nanotechnology and biotechnology for improving and sustaining crop production. These integrated topics include molecular studies (*via* biotechnology) and nanotechnology (through using nano-nutrients or nanomaterials) in the field of plant nutrition. This relationship also has paved the way to develop and set up new techniques in nano-biotechnology in precision, speed, and reliability manner (Niazian et al. 2021). Thus, many applications could be used in the plant nano-biotechnology such as nano-biofertilizers, nano-biotechnology for plant biotic/abiotic stresses, for plant genetic engineering, and nano-toxicology.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication

All authors declare their consent for publication.

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Conflicts of Interest:

The author declares no conflict of interest.

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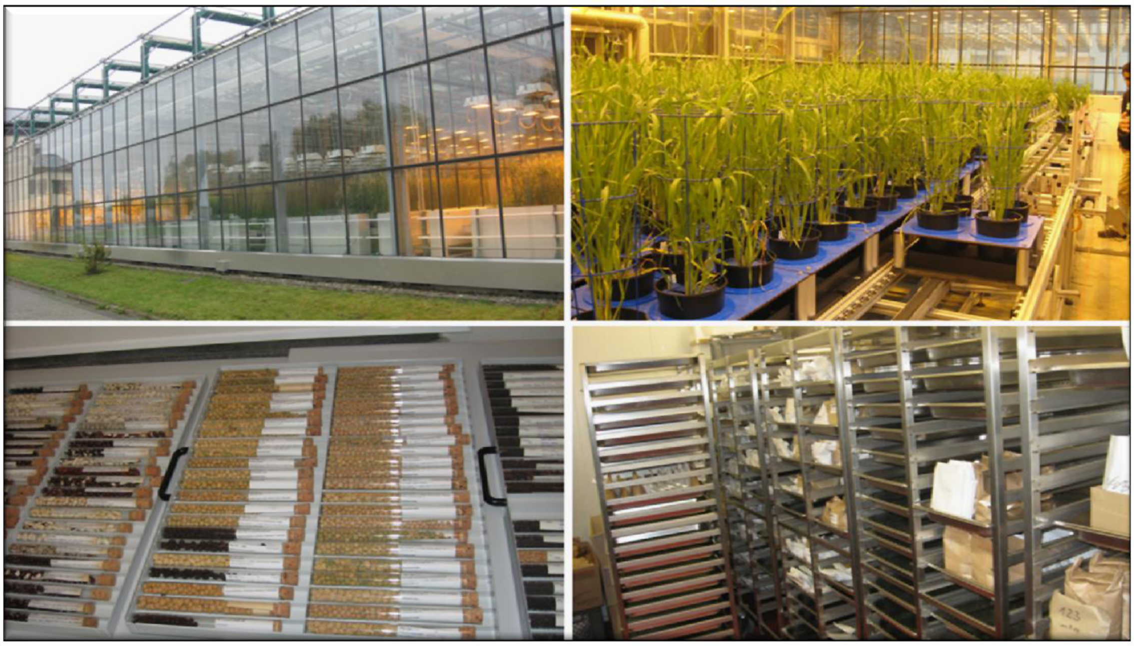

Fig. 1. Some photos were taken by El-Ramady during his attending the International Conference of German Society of Plant Nutrition “Plant Nutrition: From Basic Understanding to Better crops” 10 – 12 September 2014 / Halle (Saale), Germany. These photos belong the gene bank at Gatersleben in Germany and the high-quality greenhouse, which uses in plant nutrition research

Authors in brief

Sarwat M. Youssef (1948-2021) was Prof. of plant nutrition. His B. Sc. was from Alexandria Uni. (1972), and his Ph. D. from Berlin Uni., Germany (1988). He was a full prof. of plant nutrition and soil fertility at Kafrelsheikh University.

Mohamed Koriem is a full Prof. of soil physics. His B. Sc. was from Alexandria Uni. (1972), and his Ph. D. from Tashkent University, Uzbekistan, Soviet Union (1984). He is working now as a retired prof. at Kafrelsheikh University, Egypt.

HassanEl-Ramady is Prof. of plant nutrition and soil fertility. His B. Sc. was from Tanta Uni. (1992), and his Ph. D. from Braunschweig Uni, Germany (2008). He is working now as a full prof. at Kafrelsheikh University, Egypt.

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