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Reveiw Article

Nanofertilizers in Wheat crop nutrition: A Review

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Abstract

Nutrient management is one of the important determinants of yield of wheat crop. The conventional practices of fertilizer management are characterized by intensive use and low efficiency which has impact on the ecological and economic cost of crop production. Nanofertilizers can prove as an efficient alternative to the present fertilizer management owing to their unique properties of smaller size, higher surface area and reactivity. The studies have indicated that nanoformulations of macronutrients as well as micronutrients are effective in enhancing yield, nutrient use efficiency and enables cost reduction. In addition, the nanofertilizers are effective in alleviating various abiotic stress as well as in increasing the chlorophyll and protein content in wheat. Nanofertilizers also hold potential for biofortification. The future of nanofertilizers lies in their further advancement to nanosensors and intelligent fertilizers. However, there is need to address certain challenges including their usage regulation and commercialization.

Keywords: Nutrient management, nanofertilizer, efficiency, yield, stress, biofortification

1. Introduction

Wheat is one of the early domesticated and staple food crops of the world. The domestication of this crop is perceived about 10000 years ago in fertile crescent of Western Asia and North Africa (de Sousa et al., 2021) (insert Ref.). The crop is grown on an area of 242.39 mha with the production of 895.18 mT (FAOSTAT, 2022) satisfying the 85% energy demand and 82% of the protein demand of the global population (Al-Juthery et al., 2022). In India, wheat stands next to rice crop with a total area of 31.12 mha and production of 109.58 mT (Indiastat, 2022). The major wheat growing nations of world are China, India, USA, Canada. The world population is expected to reach 10 billion by 2050 which definitely calls for getting an increase in the wheat production so as to satisfy the energy and protein needs. If we see the rate of increase in production of the wheat crop, there has been increase of 2.1% in 1966-77 after green revolution, which further increased to 3.0% in 1977-85, however, it has reduced further to the 1.3% in 1985-97 which is less than the 1.5% of the preGreen revolution era (Tandon and Sethi, 2006). In the recent past only 0.9% growth in wheat production has been achieved (Salim, 2020). It is important to look into the principal causes of reduction of the wheat production so as to reverse the causes systematically. Though there are several reasons being attributed to the yield reduction including heat stress, degraded soil health due to intensive cropping and tillage and rising biotic stress (Jasrotia et al., 2018), crop nutrition in wheat is an essential aspect. Pre-Green revolution has seen the negligible fertilizer usage; however, with the introduction of Green revolution, there has been introduction of high yielding dwarf varieties which were accompanied with the use of higher doses of fertilizers and irrigation. Now with time, there has been increased difference between the input use cost and return impacting the overall profitability of the wheat cropping (Dhanda et al., 2022). Land degradation due to intensive farming practices and excess input use is another reason for the reduction in the yield and output (Mythili and Goedecke, 2016). It can't be neglected that there is strong correlation between the food grain production and fertilizer usage (Jayara, 2022). The number of florets per spikelet which determines the number of grains has direct correlation with the nutrient supply to the plant. Fertilizer application is essential to replenish the soil nutrient pool. However, the present times fertilizer use is associated with higher consumption compared to the yield enhancement, thus, characterized by the lower nutrient use efficiency (NUE). Overall NUE for the primary nutrients is less than 50% in conventional fertilizers (Subramaniam et al., 2015; Salim and Raza, 2020). The excess application of chemical fertilizer for higher yields is common practice since nutrient is most yield limiting element (Salim and Raza, 2020). Excess and imbalanced application of fertilizers has led to the emergence of micro nutrient deficiency. There is increased deficiency of iron, sulphur, zinc, boron and manganese in some wheat growing areas of South Asia (Jasrotia et al., 2018). Soil application of the fertilizers also leads to the reduced NUE as these become more prone to fixation and volatilization losses depending on the soil characteristics. Eutrophication and contamination of water bodies is additional problem with loss of nutrient. The beneficial microflora is also impacted with the excess use of fertilizers (Duhan et al., 2017). This calls for devising the alternate mode of nutrient delivery in wheat crop so as to address these issues. Nanotechnology is one such area which can reduce the amount of fertilizer, increase the NUE and meet out the nutritional demands of wheat crop.

Nanotechnology is the science of tiny things and refers to the study of particle in size range of one-billionth. Its use extends to the various fields including medicine, electronics, physics, chemistry, pharmaceuticals and now extending to the field of agriculture. Another definition of nanoparticle in agriculture is size dimension of 10 to 1000 nm or below 1000 nm, provided these are colloidal particulates simultaneously (Mukhopadhyay, 2014; Manjunatha, 2016). The smaller size of the nanoparticle imparts unique properties and consequent applications in the various fields. The major changes in the properties of nanoparticles are increase in surface area, cation exchange capacity, ion adsorption, complexation and different surface composition, reactivity, types and densities of sites, higher entropy in colloidal state which can be favorably utilized in agriculture (Mukhopadhyay, 2014; Chippa, 2019). The application of nanotechnology in the field of nutrient management has potential to improve the agricultural landscape.

Nanofertilizers are either nutrient in form of nanomaterials or nutrients are encapsulated inside them or these are carriers/ additives for the minerals (Usman et al., 2020). Fertilizers in form of nanoformulations possess the properties of controlled and timely release, higher solubility, effectiveness, stability, improved targeted delivery with desired concentration, safe and easy disposal and reduced toxicity (Pramanik et al., 2020). Nanostructured material such as chitosan, zeolites, nanohydroxyapatites and clay minerals can be used to develop fertilizers for soil or foliar application and their interaction with nutrient can be utilized e.g. urea modified with nanohydroxyapatite particles can serve as slow release fertilizer supplying nutrient upto 60 days (Chippa, 2019; Pramanik et al., 2020; Usman et al., 2020). Presently there is availability of natural or synthetic polymers for coating for slow release fertilizers such as biodegradable chitosan nanoparticles, kaolin and biocompatible nanoparticles (Duhan et al., 2017). The slow release of fertilizer nutrients especially beneficial where the nutrients are lost in form of volatilization, leaching or denitrification in case of nitrogen fertilizer use or reversion in case of phosphate fertilizers. The problem of leaching and fixation also extends to potassium fertilizers depending on texture of the soil (Dhillon et al., 2019; Dianjun et al., 2022). The majority of micronutrients are available at lower pH, thus spray of nanoparitcles can prove superior for them. Nanomaterial encapsulation on fertilizer binds more strongly due to higher surface tension (Pramanik et al., 2020). Some of the additives in fertilizers such as nano silica and nano titanium dioxide improve the plant resistance to biotic and abiotic stress (Duhan et al., 2017).

2. Nanonutrition in wheat

2.1 Macronutrients

Application of nutrients in nano form will lead to the reduction in the cost as well as increase in efficiency of the nutrient use (El-Saadony et al., 2021). The research evidences has shown that application of nano nutrients leads to yield advantage. Multinutrient mixture in nano form proved superior in terms of the yield (15% increase), chlorophyll (15% increase) and protein content

(6% increase) than the conventional form and even the application of only nano NPK (8.5% increase) proved to be have significantly higher yield than multinutrient mixture in conventional form (Al-Juthery et al., 2018). All the vegetative growth parameters, yield, protein content, nutrient uptake and agronomic efficiency increased significantly with the application of nanofertilizers along with amino acids than combination of mineral and amino acid or mineral and nano fertilzer or nanofertilizer alone (Kandil et al., 2017; Al-Juthery et al., 2019a). Combination of nano chelated NPK, nano micro-nutrients and yeast extract has synergistic effect resulting in significant enhancement in wheat yield and nutrient uptake (Al-Juthery et al., 2020). Nano formulation of lithovit, a rich source of calcium, magnesium and silica when sprayed at concentration of 400 ppm resulted in the significantly higher durum wheat yield with simultaneous increase in nitrogen fertilizer dose when compared to control especially under deficit irrigation conditions (Morsey et al., 2018). Lower concentration of Chitosan-Nano NPK particles in increasing the vegetative and reproductive parameters, increased yield, increased polysaccharide content, however, reduced total soluble sugar and protein content in grain, increased total P and K content in grain than their higher concentration and normal NPK application and nanofertilization also led to the reduction in the life-cyle of wheat crop by 23.5% (Abdel-Aziz et al., 2016; Abdel-Aziz et al., 2018). Average yield gain of 16% was reported with three sprays of nano P, K and Zn (different treatments) with 75% of RDF than one spray with 100% RDF (Meena et al., 2021). Similarly, Abdelsalam et al (2019) reported significant increase in the yield attributing characteristics and grain yield when there was application 75% Nano NPK + 25% mineral NPK than 100% of each alone or 50% of each in combination. Nano formulations of NPK fertilizers along with different levels of fertilizers has reported significantly higher nitrogen, phosphorus and potassium use efficiencies compared to RDF alone in wheat crop (Mehta and Bharat, 2019). Chitosan nanoparticles nano Nitrogen when applied with mineral Nitrogen reported significantly higher grain yield and yield attributing characteristics compared when mineral nitrogen dose was doubled (Saad et al., 2022). Under drought stress, nitrogen in form of chelated nano nitrogen resulted in higher grain yield with lesser dose of nitrogen in wheat (Astaneh et al., 2018). Biofertilizer loaded on nanoparticle led to at par NPK uptake even with half of the recommended dose of these fertilizers when compared to full dose in wheat crop (Hasan and Saad, 2020). The yield gain of 5.35% was reported when nano zinc and nano nitrogen were applied along with the organic sources of nutrients compared to the conventional NPK along with zinc (Kumar et al., 2022).

2.2 Micronutrients

Application of micronutrients (Fe, Zn and Cu) in combination has reported the significant increase in the vegetative parameters, yield attributing parameters, grain yield and chlorophyll content (Al-Juthery et al., 2019b). Similar increase was reported with application of increasing concentration iron nanofertilizer (Hanon Mohsen et al., 2022). 20-40 nm iron oxide nanoparticles were found to be effective in terms of uptake, translocation, increased biomass and chlorophyll content (Al-Amri et al., 2020). Seed treatment followed by the foliar application zinc nanoparticles reported significant increase in grain yield and yield contributing characters than application as seed treatment or foliar spray alone and the application of zinc sulfate at similar stages (Prajapati et al., 2018). Similarly, Nanozinc @ 400mg/lt along with recommended dose of nitrogen proved superior in stimulating plant growth and yield than 600 mg/lt dose (Seadh et al., 2020). Abdelaziz et al. (2020) reported nil Zn-P antagonistic interaction when nano zinc was applied to highest dose along with 100% phosphorus and simultaneously increase in the yield and quality parameters including protein and carbohydrate content in wheat. Iron nanochelated fertilizer @ 2.5kg/1000 lts of water reported significantly higher yields compared to higher concentrations in wheat crop under semi-arid conditions of Iran (Rezaeei et al., 2014). Application of iron and zinc oxides reported increase in enzymatic (catalase and polyphenoloxidase) activities and grain yield under saline conditions (Babaei et al., 2017). Similar role of zinc nanoparticles in alleviating salinity stress in wheat which was reflected in its increased yield, chlorophyll content and vegetative parameters was reported by Adil et al. (2022). Similarly, under late sown conditions, there was increase in plant height with increase in nanobiofertilizer concentrations (Mardalipour et al., 2014). Nano fertilization in form of nano iron or nano zinc or combination of both resulted in higher yield compared to control under severe water limiting conditions in wheat

(Seyed Sharifi et al., 2020). Similar role of Zn+Fe+Mn nanochelates along with one supplementary irrigation in increasing grain yield by 86% than with only one supplementary irrigation was highlighted by Moitazedi et al. (2022). Application of Chitosan Zinc nanoparticles along with urea reported increased zinc, iron and protein content in grain even when applied at 10 fold lower concentrations compared to conventional zinc sulfate, thus, hold potential for biofortification (Dapkekar et al., 2018). Similar potential for biofortification was reported by Munir et al. (2018) where increasing concentration of ZnO nanoparticles for seed priming resulted in increased grain Zn concentration in wheat and by Ghafari and Razamjoo (2013) where nano iron oxide even at lower concentration were more effective in increasing grain iron and protein content than iron chelates and iron sulphate.

3. Future Research Potential in nano nutrition of wheat

The field of nanofertilizer is revolutionary in terms of optimizing the nutrient dose requirement and its use efficiency in agricultural crops. Further there is need to develop intelligent fertilizers which can sense chemical and physical stimuli which may be in form of ethylene production, rhizosphere acidification in response of nutrient deficiency (Usman et al., 2020). Nanosensors is another advancement in the crop nutrition where there is potential of real time monitoring the fertilizer use and increasing efficiency. Gold nanoparticles, copper nanoparticles, carbon nanotubes and silver nanoparticles are widely studied as sensor for real time monitoring of crop growth and development (He et al., 2019). Biofortification of wheat through nanofertilizers is a efficient and cost effective agronomic approach compared to costly and time taking breeding and biotechnological approaches (Al Juthery 2022). Nanofertilizers can be further amended for their better uptake and translocation. Modification in the nanofertilizers through magnetization has proved to be effective in reducing number and strength of hydrogen bonds and increasing surface area, reducing surface tension and viscosity, thus, nutrient loaded water molecules has better penetration through cell wall and better absorption by the plants (Yasir, 2021). However, there are need to address certain issues related to the nanofertilizers. Commercialization challenges arising due to higher cost which needs economies of scale for proportionate saving of cost gained with increase in production and other issues of safety, consumer acceptance, government regulations and intellectual property need to be addressed (Cheng et al., 2016). It has been reported that increase exposure of nanoparticles in wheat resulted in increase in mitotic activity resulting into the abnormal cells and chromosomal aberration (Abdelsalam et al., 2019).

Conclusion

From the literature review, it can be inferred that nanofertilizers are effective in increasing yield and simultaneously reducing the fertilizer use in wheat. In addition to this, these nanoparticles increase the metabolic activity within the plant and thus, increase chlorophyll content and quality parameters. The nanofertilizers are also helpful in alleviating the abiotic stress in wheat. Nanoferitilizers are also suited for biofortification of wheat with lower doses of fertilizers. However, there is need to address certain challenges in form its safety, cost and acceptance.

Author Contributions

Collection of literature: ASJ, RK and PP; Preparation & writing of manuscript ASJ; Proof reading & finalisation of manuscript ASJ, RK and PP.

Ethical Approval

NA.

Conflicts of Interest:

The authors declare no conflict of interest.

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