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Review

Budding trends in integrated pest management using advanced micro- and nano-materials: Challenges and perspectives

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ABSTRACT

One of the most vital supports to sustain human life on the planet earth is the agriculture system that has been constantly challenged in terms of yield. Crop losses due to insect pest attack even after excessive use of chemical pesticides, are major concerns for humanity and environment protection. By the virtue of unique properties possessed by micro and nano-structures, their implementation in Agri-biotechnology is largely anticipated. Hence, traditional pest management strategies are now forestalling the potential of micro and nanotechnology as an effective and viable approach to alleviate problems pertaining to pest control. These technological innovations hold promise to contribute enhanced productivity by providing novel agrochemical agents and delivery systems. Application of these systems engages to achieve: i) control release of agrochemicals, ii) site-targeted delivery of active ingredients to manage specific pests, iii) reduced pesticide use, iv) detection of chemical residues, v) pesticide degradation, vi) nucleic acid delivery and vii) to mitigate post-harvest damage. Applications of micro and nano-technology are still marginal owing to the perception of low economic returns, stringent regulatory issues involving safety assessment and public awareness over their uses. In this review, we highlight the potential application of micro and nano-materials with a major focus on effective pest management strategies including safe handling of pesticides.

Contents

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1. Introduction

A significant proportion of a nation's economy relies on its agriculture and also vitally contributes to the world's food basket. Constantly expanding population coupled with changing environmental conditions exerts pressure on agriculture to augment food production in order to satiate a greater demand of food supply (Godfray et al., 2010; McClung, 2014). The advent of synthetic pesticides and fertilizers, the major contributors to the green revolution, has indeed brought about transformational change in the agriculture sector. These strategies have paved their way in modern agriculture due to the lack of sufficient inherent quality of the crop plants in sustaining environmental stresses, e.g. pest invasion.

Since 1940 synthetic pesticides provided an effective solution to control pest populations on crop plants. Losses due to the insect pests are estimated to be 27–42% on crops after application of synthetic pesticides, as opposed to >83% losses in the untreated crops (Oerke and Dehne, 2004). However, in the due course of time, several insects have developed resistance to numerous pesticides (Dawkar et al., 2013). Further, excessive use of chemical pesticides (>2 million tons/year) has caused detrimental effects on the ecosystem raising concerns to safeguard crops in an eco-friendly manner (Köhler and Tribskorn, 2013; Van Den Bosch et al., 2011). Thus to address these challenges, 'integrated biotechnological approaches' and 'sustainable intensification techniques' are being explored (Tilman et al., 2011). An adaptation of biotechnological approaches to suppress pest populations involves modification of the living organisms and their bioactives. Towards this, transgenic plants expressing insecticidal compounds have captured significant attention around the globe. A classical example is the genetically engineered crop plants expressing cry toxin(s) of *Bacillus thuringiensis* (Romeis et al., 2006). Development of transgenic plants further offers gene-pyramiding by expressing proteins with a different mode of actions or by domain swapping to maximize efficacy on the target insect pests (Dunse et al., 2010; Carrière et al., 2015). Although, genetic manipulation imparts an excellent opportunity to develop improved biopesticides, its application has been limited due to the stringent regulatory guidelines and public acceptance over their use. In addition, various natural compounds have been identified as potent deterrents, growth inhibitors, and toxins against insect pests *in vitro*. But substantial studies related to their field applications are lacking due to various environmental and other constraints. This has generated an immediate requirement to harness an alternative technology that can offer eco-friendly, cost-effective, and sustainable solutions towards pest control.

Advancements in material science has offered flexible processes to design varying size of micro and nanostructures yielding desired features (Fig. 1). Industrial application of these materials reveals their innumerable advantages in various facets of science including agriculture. Micro and nanoparticles (MNPs) if applied prudently can help to leverage biotechnological expedients via encapsulation, adsorption or conjugation. This shall also provide benefits of safe handling of chemical pesticides by achieving precise and targeted delivery. Application of insect controlling active agents in the field suffers from fast evaporation, runoff, and UV degradation. Towards this, identification of MNP based delivery systems are the key as they can offer: (i) enhanced activity against a wide spectrum of pests, (ii) greater stability and retention in external environmental condition and (iii) improved uptake (Glare et al., 2012). Furthermore, these tools are anticipated to enhance the field conditions by reducing pest burden and mediating 'smart' delivery of active ingredients in terms of targeted and controlled release of agrochemicals and biological agents. Other advantages include their use as nanosensors-sensing chemical residues, as nanocides, in reducing pesticide use, facilitating pesticide degradation, and assist nucleic acid transfer targeted against insects (Fig. 2). Taken together, implementing sustainable biotechnological approaches with the application of novel materials anticipates a paradigm shift in global crop protection.

In the following sections, we focus on cataloguing developments in advanced micro and nano-based pest management strategies that may be suited for agronomical applications. In addition, our attempt was to cite challenges and recent advances in the burgeoning use of active ingredients by exploiting unique properties of novel materials towards pest control. For the interest of the readers, a brief section on the application of nanoparticles as residue detection and pesticide degradation have also been included from the perspective of environmental concern.

2. Interaction of NPs with insect physiological status: an essential and important aspect remained unexplored

In line with the focus of the review, control of agricultural pests by nano-biotechnological means offer unprecedented advantages. Most of the devastating agricultural pests belong to two major classes named Lepidoptera and Coleoptera, responsible for major losses of field crops and stored grains. Herbivore insects depending on their feeding spectrum are divided into 'generalists' that feed on a variety of plants belonging to different families and 'specialists' that are confined to a single species of plant. In this way different insects have evolved distinct feeding habits which further determine their physiological status that varies with the diet composition. Studies have revealed that a particular insect possesses the capability to modify its biochemical composition when fed on different diets that enables them to detoxify plant defensive compounds while providing better opportunity for the utilization of nutrients (Dawkar et al., 2013; Stam et al., 2014). This presents a challenging prospect to devise a sustainable and targeted strategy for the control of particular pest population in the different environment and crops.

Applied technology of MNPs in the pest management has been gathering attention across the globe for their wide spectrum of tunable physico-chemical properties. Despite the advantages