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Nanofibers for Sustainable Agriculture: A Short Communication

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Abstract

Nanofibers could be defined as the fibers which have their diameters in nanometric range. These nanofibers have applied to many fields including the biomedical, pharmaceutical, environmental, and agricultural sectors. The previous fields have increased demand for eco-biodegradable sustainable materials that can use with high superior physical and mechanical properties like nanofibers. The medicinal and pharmaceutical fields have more attractive forces for investment compared to agriculture, which its investments in field of nanofibers still need more efforts. Concerning the agricultural field, nanofibers have been used for coating seeds, for plant protection, for encapsulation of agrochemicals, and for the filtration in irrigation systems. On the other hand, many applications of nanofibers in the environment could be adapted including air and water filtration, environmental sensing, water/wastewater treatment, heavy metal removing, for cosmeceutical purposes, and for antimicrobial treatment. However, more research should be undertaken to investigate different aspects of nanofibers on the agro-environment. There are still many unanswered questions about the impacts of nanofibers on soil biology and its quality. Further work is also required to establish the standardization of nanofiber-amendment for soil and water conservation in frame of sustainable development.

Keywords: Nanotextile, Nanomedicine, Nano-priming, Electrospin technique, Nanoremediation

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1. Applications of nanofibers in agriculture

Agricultural sector is considered one of the most important sectors in our life, which supply us with food, feed, fiber, and fuel. This sector may suffer from many sources of losses due to many reasons including abiotic stress, pathogen infestation, and decline the soil fertility. To overcome the previous problems, several applications of the nanotechnology in agricultural field have been used to protect the plant from different abiotic/biotic stresses and enhance crop production (Bose 2021). Nanofibers are nanotechnological products, which could be defined as *one-dimensional nanomaterials whose diameter range from tens to hundreds of nanometers and are produced using a broad range of natural, synthetic, and hybrid polymers* (Bose 2021). The main methods for producing the nanofibers may include non-electrospinning techniques (i.e., phase separation, template synthesis, drawing, and self-assembly), electrospinning and hydrothermal techniques (Malik et al. 2020; Naidu et al. 2021). Nanofibers have many benefits that can use in several fields in our life (Table 1).

2. TABLE 1: The main applications of nanofibers including food, agricultural and other sectors

Main applications according to different sectors	References
Applications for food industry	Noruzi (2016); Prakaash et al. (2021)
1- Nanofibers for beverage industry	Leena et al. (2020)
2- Nanofibers for food packaging industry	Duan et al. (2021); Forghani et al. (2021)
3- Nanofibers for encapsulation of food materials	Ajalloueian et al. (2022)
4- Nanofibers for food freshness indicators	Forghani et al. (2021)
5- Nanofibers for food preservation	Shi et al. (2021)
Applications for agricultural sector	Bose (2021)
1- Nanofibers for coating seeds	Farias et al. (2019); Sivalingam et al. (2021)
2- Agro-wastes for production nanofibers	Urbina et al. (2021)
3- Nanofibers-based filters for irrigation systems	Márquez et al. (2020)
4- Nanofibers for plant protection	Osanloo et al. (2020); Meraz-Dávila et al. (2021)
5- Nanofibers for encapsulation of agrochemicals	Liu et al. (2021); Mirheidari et al. (2021)
Environmental applications	Raza et al. (2021)
1- Nanofibers for air and water filtration	Naragund and Panda (2021)
2- Nanofibers for antimicrobial treatment	Yavari Maroufi et al. (20121)
3- Nanofibers for environmental sensing	Sonwane and Kondawar (2021)
4- Nanofibers for water/wastewater treatment	Sakib et al. (2021)
5- Nanofibers for heavy metal removing	Xia et al. (2021); Yadav et al. (2021)
6- Nanofibers for cosmeceutical purposes	Laosirisathian et al. (2021)
Pharmaceutical applications	Dodero et al. (2021); Pandey (2021)
Nanofibers based drug delivery (Anticancer, antimicrobial, transdermal drug delivery)	Balusamy et al. (2020); Kumar et al. (2021)
Anti-inflammatory drugs, neuroprotective drugs	Haidar et al. (2021)
Biomedical applications	Karthega et al. (2020); Urbina et al. (2021)
Wound-healing systems, Scaffolds, Blood vessels Rhinosinusitis treatment, Facemask, skin and vascular tissue engineering	Malik etal. (2020); de Carvalho and Conte-Junior (2021); Ghajarieha et al. (2021); Rivelli et al. (2021); Zhong et al. (2021)
Nanofibers for textiles	Kubera et al. (2021); Mallakpour et al. (2021)
Smart nanotextiles for sustainable agriculture	De Jorge and Gross (2021)

The main applications of nanofibers may include the following sectors food industry (food packaging industry, beverage industry, encapsulation of food materials, food freshness indicators, and food preservation), biomedical purposes (wound-healing systems, scaffolds, blood vessels, rhinosinusitis treatment, facemask, skin and vascular tissue engineering), environmental issues (air and water filtration, antimicrobial treatment, environmental sensing, water/wastewater treatment, heavy metal removing, and for cosmeceutical purposes), pharmaceutical applications (drug delivery, anti-inflammatory drugs, and neuroprotective drugs), and agricultural field (coating seeds, nanofibers-based filters for irrigation systems, and encapsulation of agrochemicals). Several reports have been published recently about the applications of nanofibers in agriculture (e.g., Meraz-Dávila; Raja et al. 2021; Saito et al. 2021). Several challenges are still facing the scientists, which may include the determination of the optimal concentration of active ingredients that could be encapsulated or deposited in the nanofiber to avoid any adverse effects on plant growth. More research is needed in order to improve the understanding of how nanofibers impact plant metabolism. The self-repair properties of nanofibers that have been used in medical research, which can also be applied to agricultural research to improve plant growth starting from the germination stage (Bose 2021).

2. Nanofiber-based filters for irrigation system

In the 21st century, water pollution has become a serious problem due to population explosion, industrialization, and urbanization. The World Health Organization (WHO) reports that 1 billion people do not have access to safe drinking water (Bai et al., 2013), and by 2050 water scarcity could affect up to 4 billion people (Ahmed et al., 2015). Electro-spun nanofiber-based membranes are a new generation of filter media in water reuse or water treatment by providing a lighter, more cost-effective, and less energy-consuming process than conventional membranes. They can swiftly and sensitively eliminate monovalent and multivalent ions and cations, salts, minerals, and waterborne pathogens (bacteria, viruses, protozoa, molds, fungus, and helminths) existing in groundwater and surface sources (Mohammad et al. 2015) due to small pore size with its narrow distribution and high porosity (Khulbe and Matsuura 2019). Moreover, their high specific surface area can improve their sorption capacity for heavy metals (Huang et al. 2014). Actually, among all the properties of the electro-spun nanofibrous membranes, the most important for water treatment purposes are pore size, surface morphology, and surface energy (Shirazi et al. 2017). First of all, the most important thing is the choice of polymeric material. Industrial-friendly, health-safe, and hydrophobic (water-resistant) polymer materials will be more promising and more effective for water treatment applications. For instance; electro-spun nanofibrous membrane was produced from a hydrophobic polymer as polyvinylidene fluoride (PVDF), and it was shown good potential for membrane distillation application. PVDF nanofiber membranes were exhibited a stable water permeation flow of approx. 21 kg m^{-2} h^{-1} during the test of 15 h, which is 100% higher than untreated fresh membrane (Liao et al., 2013). Other hydrophobic polymers such as polyvinyl butyral (PVB), polyvinyl formal (PVF), polyvinyl acetate (PVAc), polycaprolactone (PCL), polystyrene (PS), acrylonitrile (AN), etc. may be good materials for electro-spun nanofibrous membrane without any hydrophobizing agents. Interestingly, nanofibrous membrane with beads was shown a higher hydrophobicity property than smooth nanofibers while the permeate flux (Tijing et al. 2014; Ke et al. 2016).

The second generation of nanofibrous filters is their functionalization (filtration, adsorption, and sterilization) by bioactive compounds, which can be achieved by doping nanoparticles, surface coating cross-linking or grafting, interfacial polymerization, layer-by-layer, self-assembly, etc. For example; graphene oxide is becoming one of the important nanomaterials for water purification due to its multi-functionality such as excellent adsorption property, antibacterial and photocatalytic abilities (Lin et al. 2019; Sundaran et al. 2019). The surface hydrophobicity and water permeability of the electro-spun nanofibrous membrane coated with graphene oxide nanosheets were dramatically improved, and the salt removal rate remained over 99.9% when used for membrane distillation (Li et al., 2020). Nanofiber membranes containing chelating agents are considered to be the most efficient tool for removing organic impurities and heavy metal ions, and also having tunable wettability is an efficient and cost-effective tool for the separation of oil from water (Wang et al., 2016). Electro-spun polyacrylonitrile (PAN) nanofibrous membrane functionalized with hydroxylamine hydrochloride which was shown a maximum adsorption capacity of 215.1 mg g^{-1} for Cu^{2+}, and 221.3 mg g^{-1} Fe^{3+} ions (Fenglin et al. 2013). Recently, some nanoparticles have been tested for the membrane functionalization of nanofibers such as silver nanoparticles, titanium dioxide, iron nanoparticles, gold nanoparticles, etc. Silver nanoparticle functionalized electro-spun PAN nanofibrous membranes have shown a high-water flux and resistance to biofouling with antibacterial effects. Silver ions are adsorbed on the cell wall after being released from the membrane, and the cell membrane kills bacteria, and the biofouling composed of deposited and attached microorganisms is also reduced (Pan et al. 2019). It is very important that functional additives should behave adsorb, sterilize properties, as well as if released into the water, it should have a positive effect on the health of plants, animals, and humans. Furthermore, nanofibers incorporating nanoparticles have an interesting and promising future. In other words, it is possible to produce higher quality and slightly functionalized water if the nanoparticles have the therapeutic and preventive effects built into the nanofibers.

3. Sustainable agriculture and nanofibers

It is well known the concept of "sustainable products" was firstly mentioned by the United Nations in 1987, which "describes the development in such a way that it fulfills the present needs without effecting the future perspectives" (Malik et al. 2020). Therefore, sustainable nanofibers also could follow the previous definition in particularly the using of nanofibers in fields of agricultural, environmental, pharmaceutical, and biomedical applications. The main sustainable use of nanofibers in agriculture could be achieved in many agricultural activities when the nanotextiles that could fabricate from the nanofibers using the electrospinning technique. Nanofibers could sustainably apply in many agricultural processes, which lead to reduce the losses in used agrochemicals (e.g., fertilizers and pesticides), and to increase crop productivity through innovative management of nutrients or phytopathogens (De Jorge and Gross 2021). Additionally, many applications in the food industry could be improved using nanofibers including food packing, encapsulation of food materials, food freshness indicators, food preservation, beverage productions, and the development of protective cloths for farmers (De Jorge and Gross 2021). This is a call by the Egyptian Journal of Soil Science (EJSS) for more articles about the nanofibers and its applications for soil and water in different point of views. Several published articles by EJSS during the last years focused on the sustainable agriculture and different applications of nanotechnology such as Elbltagy et al. (2021), Mandal and Ghosh (2021).

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