www.envsciarch.com

ENVIRONMENTAL SCIENCE ARCHIVES

REVIEW

OPEN ACCESS

Fungi: The Next Generation of Biofertilizers

Dina E El-Ghwas, Waill A Elkhateeb, Ghoson M Daba

[1]Chemistry of Natural and Microbial Products Department, Pharmaceutical Industries Institute, National Research Centre, Dokki, Giza, Egypt 12622

Correspondence and requests for materials should be addressed to WAE (email: waillahmed@yahoo.com)

Received: 12-11-2022

Accepted: 29-12-2022

Published: 03-01-2023

Abstract

Understanding the negative impacts of using chemical fertilizers on living organisms and the environment, in general, has encouraged finding natural alternatives. Hence, biofertilizers are applied through soil or seed and are prepared from promising microbial strains (living or dormant cells) that help economically important plants in taking nutrients by interacting with their rhizosphere. Fungi are famous contributors in this field due to their ability to live in different ranges of environmental habitats and carry out processes such as nutrient cycling and decomposition of organic matter. However, many types of interactions were reported between fungi and other organisms as ants or microorganisms as bacteria. In this review, we focus on understanding what biofertilizers are, how they act and what type of interactions are noticed among them. Moreover, the classification of biofertilizers and some of their carriers are highlighted. Furthermore, we introduced examples of some fungal genera that are used as promising biofertilizers.

Keywords: Biofertilizers; Fungi; Bacteria; Phosphorus solubilizing; Nitrogen fixation

Introduction

With the rapidly increasing population, the environment is getting disturbed due to urbanization and industrialization. It is difficult to feed the entire population of the world which is significantly increasing day by day (Bhargava et al., 2019a). The natural systems have been modified by humans due to the production of food globally. The use of fertilizers has made it possible to meet the demands of the world's food supply. But due to this practice of excessive utilization of fertilizers, the environment has been affected to a great extent. It has led to the contamination of groundwater, affecting the quality of soil and biodiversity (Kumar et al., 2020b). Further, plants face certain environmental stresses, both biotic and abiotic, which have a negative impact on the yield and growth of crops. Abiotic stresses which include temperature of environment, salinity, pH of the soil, etc., have always affected agriculture (Bhargava et al., 2019b). Therefore, instead of utilizing chemical fertilizers, an alternative method to deal with these situations is to elevate the use of biofertilizers (Kumar et al., 2020a). Biofertilizers need to be preferred over chemical fertilizers as they are cost-effective, secrete growth hormones, uplift crop yield, improve nitrogen fixation, and do not cause harm to the environment (Mahanty, 2017). Therefore, the use of beneficial microbes as biofertilizers has become an increasing area of research in agriculture and life sciences owing to the role they play in food security and sustainable agro-crop production. Their interactions and activities lead to increases in crop yield, the earth's geochemical, stability, climatic, and biogeochemical cycles (Hansel et al., 2008). This review focuses on fungi biofertilizers for the next generation.

Biofertilizer

In the rhizosphere, there is a large number of microorganisms present in the soil. There is an interaction between plants and microorganisms in the rhizosphere. Some of these microorganisms have a functional relationship with plants. This relationship is beneficial for the plants in different ways such as enhancing their growth and providing resistance to environmental stress which include contamination of heavy metal, and deficiency of nutrient and water (Sharma et al., 2018). Therefore, biofertilizers are those preparations carrying living or latent cells of potent microbial strains that help economically important plants in taking nutrients through interacting in the rhizosphere.

e-ISSN: 2583-5092

Biofertilizers are a combination of organic matter and useful microorganisms. Xiong (2017) reported that organic matter acts as a niche for microorganisms and also helps in recycling. The important nutritional elements became available with the help of these microorganisms via various biological mechanisms. Now, biofertilizers are an important part of the system which supplies nutrients and have a crucial role to play in improving the yield of crops (Singh and Vats, 2019). They are gaining popularity in different parts of the world as they are found to protect the roots of the plant from pathogens present in the soil along with the enhancement in the fertility of the soil. The microbiota of the bulk soil is modified by the addition of biofertilizers (Tandon and Vats, 2016). For the management of integrated nutrients, using biofertilizers is considered one of the main components, due to being a cheap and renewable source of nutrients for the plants. Several microbial species and their association with crop plants are studied for their ability to be used as biofertilizers.

Fungal Biofertilizers

Mycological studies have shown that fungi live in a wide range of environmental habitats and carry out processes such as nutrient cycling and decomposition of organic matter. Recently, applying fungi to arable land in order to improve the quality of the soil has attracted serious attention due to its promising results (Bagyaraj and Ashwin 2017). In this process, fungi colonize the plant roots region (rhizosphere) in order to promote growth. This phenomenon usually increases the efficient distribution of essential nutrients to the target crops while also maintaining soil inhabitants, owing to their ability to adopt various forms in response to unfavourable conditions. Kumar et al. (2018) in their work reported that these fungi could be used in seeds, applied on plant surfaces or in the soil to stimulate growth. They have also been implicated in continuously helping in the release of nutrients through their metabolism (Malusa et al., 2012). Some of the common microorganisms usually used as biofertilizers are nitrogen-fixing agents (Odoh et al., 2019), plant growth-promoting rhizobacteria (Yadav et al., 2018a), potassium solubilizers (Kour et al., 2020), phosphorus solubilizers (Yadav et al., 2017a), cyanobacteria and endomycorrhizal and ectomycorrhizal fungi (Itelima et al., 2018). Basically, these microorganisms have the ability to produce an assortment of potent extracellular enzymes that can break different organic components (Frąc et al., 2018).

Fungal–Fungal Interactions

In this process, fungi make an obligate symbiotic relationship with leaf-cutting ants. Following a series of systematic steps, plant leaves are cut and transported to the nest where they are cleaned up, processed, and utilized as substrate. At the same time, fungi utilize leaves by converting its biomass into nutrients for the worker ant population and their larvae. This is however achievable due to the activities of fungi living in the underground chambers (Van Bael et al., 2011). Moreover, this process undermines the behaviour of leaf-cutter ants including plant fungal endophytes. Similarly, they also synthesize organic compounds with antimicrobial and insect-repellent characteristics (Borges et al., 2009). These compounds thus provide an avenue for microbial competition within the community, while altering the chemical and adaptive defense system (Pettit, 2009). Additionally, Van Bael et al. (2011) have reported the associative roles of some fungal endophytes on leaves and how they enhanced lignin deposition in plants' cell walls.

Bacterial–Fungal Interactions

Ecological studies have revealed that bacteria and fungi co-habit through their assemblage into complex and dynamic co-evolving groups. Fungal and bacterial communities are found in all ecosystems (Scherlach et al., 2013), and the interactions between these microbes play a huge role as they are considered vital players in driving activities such as biochemical cycles and contributing in a significant way to plant and animal pathogens (Deveau et al., 2018). These agents have been utilized for the production of food and its processing (Odoh et al., 2017), pharmaceutics and antibiotics synthesis, biotechnology and production of metabolites (Frey-Klett et al., 2011). Also, in characterizing the bacterial fungal interaction, understanding microbiomes using molecular tools, chemical and microbial ecology, genomics, and biophysics are essential (Bergelson et al., 2019).

Arbuscular mycorrhizal fungi and bacteria (plant growth promoting rhizobacteria) association have been reported to promote crop growth (Pathak et al., 2017). As reported by Philippot et al. (2013), *Bacillus* sp., *Pseudomonas* sp. and Arbuscular mycorrhizal fungi interaction proffers strong viability and causes important enhancement in field study when applied singly or in the combined application (Pathak et al., 2017). Although this association has a positive influence on crop yield, it also enhances soil nutritional status and soil microbial biodata.

Biofertilizers Classification

Biofertilizers are composed of diverse microorganisms that when administered to plants, and seeds stimulate their growth. Both nitrogen fixation and phosphorus solubilization are important biological processes (Singh, 2016). Biofertilizers also prevent the plants from getting infected by several diseases, e.g., *Fusarium* wilt disease (Li, 2017). Figure 1 shows the classification of biofertilizers on the basis of function and nature.

Phosphorus is an important macronutrient. Due to reduced levels of soluble phosphate in the soil, the plant is not able to grow properly. To overcome this issue, P-fertilizers were commonly made into use. In spite of this, a very small quantity of phosphorus is used up by plants and most of it is precipitated in the form of complexes of aluminium, iron, and calcium. Phosphorus uptake from soil by plants is not easy. However, some microorganisms are capable of solubilizing phosphorus acting as biofertilizers. They convert the phosphorus which is insoluble into soluble form which is readily taken up by the plants. This approach of using phosphorous biofertilizers is responsible for improving the yield of agriculture in several countries (Wang, 2015). Nitrogen is one of the vital nutrients utilized by plants. Nitrogen fertilizers are used to obtain the necessary nitrogen required for development and growth of plants. Such fertilizers have bad impacts on the environment when applied in excess amounts. Therefore, biofertilizers are used as safer alternatives in order to satisfy plants' needs (Vats et al., 2019). Also, plants need help in order to take atmospheric nitrogen. Hence, it is first converted into ammonia by the process of nitrogen fixation and then the assimilation takes place. The nitrogen-fixing microorganisms fix nitrogen with the help of nitrogenase enzymes. These microorganisms are present in biofertilizers (Mahanty, 2017). They also assist in water and mineral absorption (Vats et al. 2012).

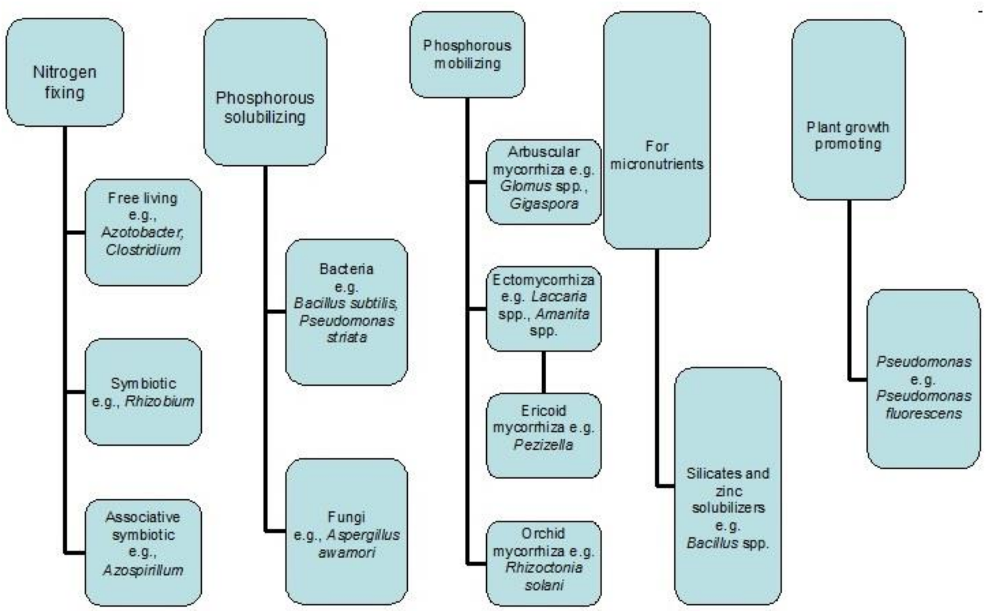

Figure (1): Classification of biofertilizers on the basis of function and nature

Carriers of the Biofertilizers

Biofertilizers are prepared using a carrier composed of microorganisms (Wang, 2015). It is considered as a transporter of biofertilizers from the manufacturing unit to the field. There are different carriers for different biofertilizers (Mahanty, 2017). Peat is applied as a biofertilizer carrier in various countries. A promising carrier should have some specific properties such as being eco-friendly, or in the form of granules or powder, able to absorb moisture, helping the microbes to grow and survive, cost-effective, and able to easily discharge the useful microorganisms into the soil.

Perlite is also an eco-friendly biofertilizer carrier used which is composed of aluminium silicate and some amount of water. It is also porous and lightweight. In order to store the biofertilizer carrier for a long period of time, its sterilizations are crucial. On the other hand, one of the methods to sterilize the carrier material is through gamma irradiation. This technique is accessible and causes limited losses during storage. Biofertilizers on carriers are preferred over free-cell as carriers provide protection to the microorganisms from environmental stress. Thereby, providing shelter to the microbes.

Fungal Biofertilizers and Agriculture

Biofertilizers are composed mainly of microbes such as fungi, algae, and/or bacteria with the ability of fixing nitrogen, adding nutrients to soil and solubilizing minerals to fulfil plant needs. They are environmentally friendly, cost-effective, and renewable sources of plant nutrients that have gained acceptance over chemical fertilizers (Kour et al., 2020). These bio-based materials play an important role in maintaining soil fertility, nutritional enrichment, and sustenance of healthy soil for generations (Mishra et al., 2015).

Mycorrhizas are unique microbes that form mutual symbiotic relationships with plant roots. They interact with these plants and enhance the uptake of phosphorus (P), nitrogen (N), zinc (Zn), copper (Cu), iron (Fe), sulphur (S), and boron (B). Some of plants with mutualistic association with mycorrhiza species include herbs, shrubs, trees, xerophytes, epiphytes, and hydrophytes (Rai et al., 2013).

Fungi used as biofertilizers

Trichoderma spp.

Trichoderma is a fungal genus commonly found in most habitats. They are predominantly found in root and soil ecosystems and are considered ubiquitous saprobes. Some Trichoderma strains interact with their plant's host, increasing their growth potential and imposing resistance against diseases and abiotic stresses (Rosa et al., 2012). *Trichoderma* spp. has been engineered over time to successfully support crops such as potatoes, corn, tomato, peanut, beans, cotton, and soybean (Sneha et al., 2018).

Chaetomium spp.

Chaetomium species exist mainly in organic compost and soil. It is a promising fungicidal agent used frequently for protective and curative purposes. Ketomium is an important secondary metabolite that is formulated from both *Ch. Globosum* and *Ch. cupreum* and acts as plant growth stimulant (Jehangir et al., 2017). As a promising strategy, *Chaetomium* spp. Can suppress bacterial and some other fungal growth through mycoparasitism, competition, and antibiosis (Marwah et al., 2007).

Penicillium spp.

Penicillium spp. are phosphorus solubilizing agents. They act as biofertilizers by enriching compost and soil quality (Sharma et al., 2013). Some of the important species in this genus are P. *bilaji*, P. *italicum*, P. *simplicissimum*, P. *oxalicum*, P. *frequentans*, and P. *rubrum* (Yadav et al., 2018b). Also, Mishra et al. (2013), suggested that a combination of *Penicillium* and *Trichoderma* increases the development of wheat and soybean under nursery conditions. Elsewhere, P. *italicum* from the rhizosphere soil also has the ability to solubilize tricalcium phosphate (TCP) and promote efficient soybean growth and production (Ram et al., 2015), while *Penicillium* spp. serves as phosphate solubilizer and general plant growth stimulator (Sumita et al., 2015).

***Aspergillus* spp.**

Aspergillus niger; this agent facilitates plant growth through root formation (bio-promoter). It improves soil quality and can be used to produce zinc solubilizing biofertilizers. Ambiphos is one of the promising biofertilizers made from *Aspergillus niger* as it secretes organic acids that help in converting insoluble phosphate into soluble form and make its uptake by plants much easier. On the other hand, the genera (A. *flavus,* A. *tubingensis,* A. *awamori,* A. *terreus,* A. *fumigates,* A. *niger,* and A. *melleus*) are able to solubilize inorganic phosphate through the production of citric acid, gluconic acid, glycolic acid, oxalic acids, and succinic acid. *Aspergillus fumigatus* which is most often isolated from compost has been reported to be potassium releasing fungus (Sharma et al., 2013).

***Gliocladium* spp.**

Gliocladium species are common saprophytes that exist mainly in soil. They are also parasites on different plant pathogens such as *Sporidesmium sclerotiorum* and *Fusarium* spp. *Gliocladium virens* has been used as a biological control agent against a wide range of soil-borne pathogens such as *Pythium* and *Rhizoctonia* under greenhouse and field conditions. It also produces antibiotic metabolites such as gliotoxin which has anti-bacterial, antifungal, anti-viral, and anti-tumor activities (Nissipaul et al., 2017).

Conclusion

Chemical fertilizers have been more popular in recent decades for use in agriculture, while biofertilizers are a more environmentally friendly option. Fungi are the most well-known among them. By preventing infections' growth and limiting some of their biological functions, fungi biofertilizers reduce the frequency of plant diseases. They create hormones and enzymes that promote plant growth in addition to enhancing the uptake of nutrients from the soil and creating bioactive substances. On the other hand, microorganisms as natural alternatives of harmful chemical biofertilizers have attracted serious attention. Fungi are promising contributors in this field with various types of interactions. Further studies are encouraged to understand the potential of these promising microorganisms in this field and their impact on plants' health.

References

Bagyaraj DJ, Ashwin R (2017) Soil biodiversity: role in sustainable horticulture. Biodivers Hortic. Crops 5: 1–18.

Bergelson J, Mittelstrass J and Horton MW (2019) Characterizing both bacteria and fungi improves understanding of the Arabidopsis root microbiome. Sci Rep 9: 24.

Bhargava P, Khan M, Verma A, et al. (2019a). Metagenomics as a tool to explore new insights from plant-microbe interface. In: Plant microbe interface. Springer, Cham, pp 271–289.

Bhargava P, Vats S and Gupta N (2019b) Metagenomics as a tool to explore Mycorrhizal fungal communities. In: Mycorrhizosphere and pedogenesis. Springer, Singapore, pp 207–219.

Borges WS, Borges EO, Bonato PS, et al. (2009) Endophytic fungi: natural products, enzymes and biotransformation reactions. Curr Org Chem 13: 1137–1163.

Daba GM, Mostafa FA and Elkhateeb WA (2021) The ancient koji mold (*Aspergillus oryzae*) as a modern biotechnological tool. Bioresources and Bioprocessing, 8(1): 1-17.

Daba GM, Elkhateeb WA and Thomas PW (2018) This era of biotechnological tools: an insight into endophytic mycobiota. Egyptian Pharmaceutical Journal, 17(3): 121–128.

Deveau A, Bonito G, Uehling J, et al. (2018) Bacterial-fungal interactions: ecology, mechanisms and challenges. FEMS Microbiol Rev 42: 335–352.

Elkhateeb WA, Akram M, Zohri A, et al. (2022) Fungal Enzymatic Cocktails Benefits and Applications. Open Access Journal of Pharmaceutical Research. 6(1): 1-8.

Elkhateeb WA, EL-Ghwas DE, AL Kolaibe AG, et al. (2021e) Yeast the Present and Future Cell Facture. Open Access Journal of Mycology & Mycological Sciences. 4(2): 1-8.

Elkhateeb WA, Elnahas MO and Daba GM (2021c) Bioactive metabolites of *Cunninghamella*, Biodiversity to Biotechnology. Journal of Pharmaceutics and Pharmacology Research, 4(3): 1-5.

Elkhateeb WA and Daba GM (2019b) The Amazing Potential of Fungi in Human Life. ARC Journal of Pharmaceutical Sciences, 5(3): 12-16.

Elkhateeb WA and Daba GM (2020) The Exceptional Endophytic Fungi, *Emericella* (Berk.) and *Phoma* (Sacc.) Genera, International Journal of Research in Pharmacy and Biosciences, 7(1): 1-6.

Elkhateeb WA and Ghoson MD (2018) Where to Find? A Report for Some Terrestrial Fungal Isolates, and Selected Applications Using Fungal Secondary Metabolites. Biomed Journal Science &Technology Research, 4(4): 1-4.

Elkhateeb WA, Kolaibe AG, Elnahas MO, et al. (2021a) Highlights on *Chaetomium* morphology, secondary metabolites and biological activates. Journal of Pharmaceutics and Pharmacology Research, 4(1): 1-5.

Elkhateeb WA, Mousa KM, ELnahas MO, et al. (2021b) Fungi against insects and contrariwise as biological control models. Egyptian Journal of Biological Pest Control, 31(1), 1-9.

Elkhateeb WA, Ghoson and M. Daba (2019a) *Myrothecium* as Promising Model for Biotechnological Applications, Potentials and Challenges. Biomedical Journal of Scientific and Technical Research, 16(3): 1-6.

Elkhateeb WA, Elnahas MO, Daba GM, et al. (2021d) Biotechnology and environmental applications of *Trichoderma* spp. Research Journal of Pharmacognosy and Phytochemistry, 13, 3.

Frąc M, Hannula SE, Bełka M, et al. (2018) Fungal biodiversity and their role in soil health. Front Microbiol 9:707

Frey-Klett P, Burlinson P, Deveau A, et al. (2011) Bacterial-fungal interactions: hyphens between agricultural, clinical, environmental, and food microbiologists. Microbiol Mol Biol Rev 75:583–609

Hansel CM, Fendorf S, Jardine PM, et al. (2008) Changes in bacterial and archaeal community structure and functional diversity along a geochemically variable soil profile. Appl Environ Microbiol 74:1620–1633

Itelima JU, Bang WJ, Onyimba IA, et al. (2018) A review: biofertilizer; a key player in enhancing soil fertility and crop productivity. J Microbiol Biotechnol Rep 2:22–28

Jehangir IA, Mir MA, Bhat MA, et al. (2017) Biofertilizers an approach to sustainability in agriculture: a review. Int J Pure Appl Biosci 5: 327–334

Kour D, Rana KL, Yadav AN, et al. (2020) Microbial biofertilizers: bioresources and eco-friendly technologies for agricultural and environmental sustainability. Biocatal Agric Biotechnol 23: 101487.

Kumar MS, Reddy GC, Phogat M, et al. (2018) Role of bio-fertilizers towards sustainable agricultural development: a review. J Pharmacogn Phytochem 7:1915–1921.

Kumar N, Balamurugan A, Shafreen MM, et al. (2020a) Nanomaterials: emerging trends and future prospects for economical agricultural system. In: Biogenic Nano-particles and their use in agro-ecosystems. Springer, Singapore, pp 281–305.

Kumar N, Srivastava P, Vishwakarma K, et al. (2020b) The rhizobium–plant Symbiosis: state of the art. In: Plant microbe symbiosis. Springer, Cham, pp 1–20.

Li R (2017) Chemical, organic and bio-fertilizer management practices effect on soil physicochemical property and antagonistic bacteria abundance of a cotton field: implications for soil biological quality. Soil Tillage Res 167:30–38

Mahanty T (2017) Biofertilizers: a potential approach for sustainable agriculture development. Environ Sci Pollut Res 24(4): 3315–3335.

Malusa E, Sas-paszt L and Ciesielska J (2012) Technologies for beneficial micro-organisms inoculation used as biofertilizers. Sci World, 1: 1-10.

Marwah RG, Fatope MO, Deadman ML, et al. (2007) Musanahol: a new aureonitol-related metabolite from a *Chaetomium* sp. Tetrahedron 63:8174–8180

Mishra DJ, Rajivir S, Mishrra UK, et al. (2013) Role of biofertilizers in organic agriculture: a review. Res J Rec Sci 2: 39–41.

Mishra S, Singh A, Keswani C, et al. (2015) Harnessing plant-microbe interactions for enhanced protection against phytopathogens. In: Plant microbes' symbiosis: applied facets. Springer, New Delhi, pp 111–125.

Nissipaul M, Sodimalla T, Subhashreddy R, et al. (2017) Novel biofilm biofertilizers for nutrient management and *Fusarium* wilt control in chickpea. Int J Curr Microbiol App Sci 6: 1846–1852.

Odoh CK (2017) Plant growth promoting rhizobacterial (PGPR): a bioprotectant bioinoculant for sustainable agrobiology. Int J Adv Res Biol Sci 4: 123–142.

Odoh CK, Amapu TY, Orjiakor IP, et al. (2017) Assessment of mold contamination and physicochemical properties of crude palm oil sold in Jos, Nigeria. Food Sci Nutr 2: 310–316.

Pathak D, Lone R and Koul KK (2017) Arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR) association in potato (Solanum tuberosum L.) A brief review. In: Kumar V, Kumar M, Sharma S, Prasad R (eds) Probiotics and plant health. Springer, Singapore, pp 401–420.

Pettit R (2009) Mixed fermentation for natural product drug discovery. Appl Microbiol Biotechnol 83: 19–25.

Philippot L, Raaijmakers JM, Lemanceau P, et al. (2013) Going back to the roots: the microbial ecology of the rhizosphere. Nat Rev Microbiol 11: 789–799.

Rai A, Rai S and Rakshit A (2013) Mycorrhiza-mediated phosphorus use efficiency in plants. Environ. Exp Biol 11: 107–117.

Ram H, Malik SS, Dhaliwal SS, et al. (2015) Growth and productivity of wheat affected by phosphorus-solubilizing fungi and phosphorus levels. Plant Soil Environ 24-61: 122–126.

Rosa H, Ada V, Ilan C, et al. (2012) Plant-beneficial effects of *Trichoderma* and of its genes. J Microbiol 158: 17–25.

Scherlach K, Graupner K, Hertweck C (2013) Molecular bacteria – fungi interactions: effects on environment, food and medicine. Annu Rev Microbiol 67: 375–397.

Sharma D, Javed S, Arshilekha PS, et al. (2018) Food additives and their effects: a mini review. Int J Curr Res 10(6): 69999–70002.

Sharma SB, Sayyed RZ and Trivedi MH (2013) Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. Springer Plus 2: 587.

Singh M (2016) Role of biofertilizers in conservation agriculture. In: Conservation agriculture. Springer, Singapore, pp 113–134.

Singh M and Vats S (2019) Mathematically designed bioprocess for release of value-added products with pharmaceutical applications from wastes generated from spices industries. Int J Pharm Sci. Res 10: 130–138.

Sumita P, Singh HB, Alvina F, et al. (2015) Fungal biofertilizers in Indian agriculture: perception, demand and promotion. J Eco Agric 10: 101–113.

Tandon S and Vats S (2016) Microbial biosynthesis of cadmium sulfide (Cds) nanoparticles and their characterization. Eur J Pharm Med Res 3: 545–550.

Van Bael SA, Estrada C and Wcislo WT (2011) Fungal-fungal interactions in leaf-cutting ant agriculture Psyche. J Entomol, 9: 1-10.

Vats S, Gupta N and Bhargava P (2019) Vulnerability of soil micro biota towards natural and anthropogenic induced changes and loss of pedospheric functionality. In: Mycorrhizosphere and pedogenesis. Springer, Singapore, pp 191–205.

Vats S, Kumar R and Negi S (2012) Natural food that meet antibiotics resistance challenge: in vitro synergistic antimicrobial activity of *Azadirachta indica*, *Terminalia chebula*, Piper nigrum and photoactivated cow urine. Asian J Pharm Biol Res (AJPBR) 2(2)

Wang HY (2015) Preparation and utilization of phosphate biofertilizers using agricultural waste. J. Integr Agric 14(1): 158–167.

Xiong W (2017) Bio-fertilizer application induces soil suppressiveness against Fusarium wilt disease by reshaping the soil microbiome. Soil Biol Biochem 114: 238–247.

Yadav AN, Kumar R, Kumar S, et al. (2017a) Beneficial microbiomes: biodiversity and potential biotechnological applications for sustainable agriculture and human health. J Appl Biol Biotechnol 5: 45–57.

Yadav AN, Kumar V, Prasad R, et al. (2018a) Microbiome in crops: diversity, distribution and potential role in crops improvements. In: Prasad R, Gill SS, Tuteja N (eds) Crop improvement through microbial biotechnology. Elsevier, Cambridge, pp 305–332.

Author Contributions
DEE, WAE and GMD conceived the concept, wrote and approved the manuscript.

Acknowledgements
Not applicable.

Funding
There is no funding source for the present study.

Availability of data and materials
Not applicable.

Competing interest
The authors declare no competing interests.

Ethics approval
Not applicable.

Citation: El-Ghwas DE, Elkhateeb WA and Daba GM (2023) Fungi: The Next Generation of Biofertilizers. Environ Sci Arch 2(1): 34-41.