INFLUENCE OF ARBUSCULAR MYCORRHIZAL FUNGI AND PLANT GROWTH PROMOTING YEAST ON GROWTH AND YIELD OF CROPS FOR SUSTAINABLE AGRICULTURE

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Abstract. This review focused on useful effects of arbuscular mycorrhizal fungi and plant growth-promoting yeast on agricultural plants as possible biological agents in increasing nutrient absorption, crop yield and tolerance to biotic and abiotic stress conditions. Chemical pesticides and fertilizers are becoming prevalent in causing environmental harm. To solve this problem, arbuscular mycorrhizal fungus and plant growth-promoting yeast are utilized. According to recent research, arbuscular mycorrhizal fungi and plant growth promoting yeast are more beneficial for improving soil health, nutrient absorption, nutrient mobilization, bioremediation, pest control, and disease management in an ecofriendly, efficient and cost effective manner than the inorganic chemicals. Arbuscular mycorrhizal fungi and plant growth promoting yeast both have distinct roles in plant growth and combining their inoculations can produce the best results. Utilizing plant growth-promoting yeast and arbuscular mycorrhizal fungi inoculation will decrease the need for chemical fertilizers and pesticides, which will result in attaining sustainable agriculture.
Keywords: *biological agent, uptake of nutrients, reduce the excess use of chemical fertilizers, yield enhancement, acts as biofertlizer*

Abbreviations. AMF - Arbuscular Mycorrhizal Fungi; PGPY - Plant Growth Promoting Yeast

Introduction

Continuous and excessive use of chemical fertilizers is harmful to the soil, the environment, and to human health and also spoil soil fertility (Naik et al., 2019). The new way of crop production causes the demand in organic fertilizers as the farmers are aiming for organic agriculture. AM fungi is the soil borne symbiotic fungi which is helpful for plants by symbiotic relations, it makes symbiosis with 80-90% of plant species and 90% of crop plants (Smith and Read, 2010) like cereals, pulses, vegetables, and horticultural plants (Kivlin et al., 2011). AM fungi increases the supply of water and nutrients such as P and N to the crop plants using extraradicle, intraradicle hyphae and arbuscules (Parniske, 2008) it can confer resistance to biotic and abiotic stress (Sun

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et al., 2018). AM fungi can be used in several crops to enhance nutrient intake, improve physiological characteristics and improve plant growth and yield. In early days yeast is only used for preparing bread, wine and beer. But role of yeast has expanded from food industry to various industries especially agriculture (Barnett, 2011). Yeast involved in several processes like breaking down of complex molecules, nutrient recycling, biodegradation of hydrocarbons. The yeast which are used in the field of agriculture which promotes the plant growth is called plant growth promoting yeast (PGPY) PGPY regulates the synthesis of phytohormones, boosting the availability of nutrients, strengthening resistance to biotic and abiotic stress, suppressing phytopathogens etc. (Nimsi et al., 2023). This review aims to give insight into combined inoculation of AM fungi and plant growth promoting yeast to attain maximum benefit for sustainable agriculture.

Arbuscular mycorrhizal fungi

The term mycorrhiza is derived from the Greek word “mukés”, meaning fungus, and “rhiza,” meaning roots, Mycorrhizal fungi grow in the roots of plants and form a symbiotic relationship known as "mycorrhiza". They come together to form a network of tiny filaments that attach themselves to plant roots in order to extract water and nutrients from the soil. Arbuscular Mycorrhizal Fungi (AMF) is one of the best options for sustainable agriculture and food security. AMF symbiosis is said to be a very old symbiosis. According to the archeological records, it is originated millions of years ago (Humphreys et al., 2010). AM Fungi are widely found in terrestrial ecosystems (Verbruggen et al., 2012). Around 80 to 90 % of vascular plant species and 90% of crops form symbiotic association with AM fungi (Smith and Read, 2010). Some families like Amaranthaceae, Brassicaceae, Cruciferae, Chenopodiaceae, Caryophyllaceae, Juncaceae, Cyperaceae, and Polygonaceae do not form association with AM fungi due to the deterrent and inhibitory compounds produced by the host crops (Brundrett, 2009). Most of the AM fungal species belonging to the phylum Mucoromycota and sub phylum Glomeromycota (Spatafora et al., 2016). Glomerales, Archaeosperales, Paraglomerales and Diversisporales are four orders of AM fungi. 11 families, 25 genera and nearly 250 species are belonging to AMF (Schüβler et al., 2001; Spatafora et al., 2016). Although many AMF species have been studied globally, the following species are most frequently used as models viz., *Rhizophagus irregularis, Gigaspora rosea, Gigaspora margarita*, *Gigaspora gigantea*, and *Funneliformis mosseae* (Schüssler and Walker, 2010). AMF is an obligate symbiont and to complete their lifecycle they need the host plant. They increase crop yield by increasing uptake of nutrients such as nitrogen phosphorus and potassium (Anderson et al., 2018). Role of AMF is not only for promoting the plant growth and protect the plants from fungal infections (Smith et al., 2010; Jung et al., 2012). Through extra and intraradical hyphae fungi can supply the nutrients like Phosphate and Nitrogen. Nutrients are absorbed by mycelium osmotrophically and penetrate more area when compared to non-mycorrhizal roots (Duponnois et al., 2011). AMF has been reported to enhance soil properties like soil aggregation, available nutrients in soil, water retention, microbial activity, N cycle, C cycle, and P cycle, and soil acidity correction, in addition to its effect on growth and promotion (Jamiołkowska et al., 2018; Parihar et al., 2020).

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Plant growth promoting yeast

Yeast is unicellular microorganisms that are inhabitants of soil and plants but exists in a lower number compared to bacteria and filamentous fungi (Yurkov et al., 2018). Yeasts are under the kingdom fungi, phylum Ascomycota and Basidiomycota. Yeast is a heterotrophic microorganism, which need carbon and nitrogen for their energy. Utilize carbohydrates to produce CO_2 and H_2O in the presence of oxygen. In absence of oxygen, they convert the carbohydrates to alcohol by the process called fermentation. Their shape and size varies depending on the species, some of the yeast species are round, ellipsoidal, oval, or cylindrical in shape. The size of the cells ranging from 3-10 µm. Adhesion and biofilm formation improves their ability to survive in competitive environment. Sexual and asexual reproduction is the two modes of reproduction. Budding is the first type of asexual reproduction; it needs suitable environmental conditions, which include temperature and nutrient availability. *Candida, Saccharomyces, Pichia* and *Rhodotorula* are the microorganisms that can reproduce through budding. *Schizosaccharomyces* are the microorganisms reproduce through fission. In extreme conditions like deficiency of nutrients, Yeast can produce spores. The shape and size of the spore is based on the yeast species (Kowalska et al., 2022). Yeast's role in agricultural ecosystems is not yet completely analysed (Fu et al., 2016) and its growing area needs to be tapped (Jeyashri et al., 2019). Application of yeast in agricultural and horticultural crops elaborated in *Table 1*.

Table 1. *Application of yeast in sustainable agriculture*

Yeast	Usage in Agriculture	References
Candida tropicales	Used as biofertilizer	Mekki and Ahmed (2005)
Candida oleophila	Control grey mould in kivi fruit	Sui et al. (2020)
Candida famata	Acts as a parasite forcontrol of *Colletotrichum gloeosporioides* by releasing enzymes	Magallon-Andalon et al. (2012)
Candida tropicalis HY	Acts as a plant growth promoter by ACC deaminase activity, IAA production and solubilization of P	Amprayn et al. (2012)
Candida tropicalis	Prevent Banana from Antracnose	Zhimo et al. (2016)
R. mucilaginosa	Degradation of insecticides like acetamiprid (AAP) and thiacloprid (THI)	Dai et al. (2010)
Pichiaanomala	Prevent fruit rot in guava	Mohamed et al. (2009)
Rhodotorula graminis (WP1) andRhodotorula mucilaginosa (PTD 2 and PTD3)	It acts as a Plant growth regulator by the production of Indole-3-acetic acid	Xin et al. (2009)
Trichosporo nasahii	Reduce antracnose infestation in papaya	Hassan et al. (2021)
Kluyveromyces walti, Pachytrichospora transvaalensis and S. cataegensis	It acts as a Biofertilizer	Agamy et al. (2013)
P. kudriavzevii	Helpful for degrading atrazine	Abigail et al. (2013)
Lipomyces starkeyi	Biodegradation of triazine herbicides	Nishimura et al. (2002)
Pichia membranaefaciens	It acts as a Biocontrol agent and Inhibit growth of Colletotrichum gloeosporioides	Zhou et al. (2016)

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AM fungi and PGPY as potential biological agents

AM fungi are said to be the natural plant growth enhancers and potential biological agents (Begum et al., 2019) and establish reciprocal symbionts with the roots of crop plants (Bennett and Groten, 2022) AMF inoculation provides more water to the crops, enhances moisture uptake and improves accumulation of dry (Chandrasekaran et al., 2019). AM fungi offered various mechanisms to the host plants to get rid of various abiotic stresses (Yadav et al., 2023). By serving an excellent bioagent AM fungi combat abiotic stress combined together with reduced inorganic fertilizers (Wang et al., 2023). In maize AM fungi resulted in higher leaf gas exchange and photosynthate under heat stress compared to uninoculated control (Mathur et al., 2018). Glomalin a super glue produced by AM fungi helps in sequestration of more carbon from the soil, aggregates more soil particles (Gomathy et al., 2018) and safeguard the soil from dessication through enhancing the water holding capacity of soil (Syamsiyah et al., 2018). Food crops can be cultivated even in the heavy metal contaminated soil due to the inoculation of AM fungi as it accumulates the heavy metals through various mechanisms and keep crops free of metal accumulation (Gomathy et al., 2022). Exploiting AM fungi as potential biological agent for plant growth in several ecosystems pave the way for organic farming lead to sustainable agriculture. AM fungi colonized plants exhibited higher antioxidant enzyme activity (Gomathy et al., 2021), increased level of secondary metabolites (Castellanos-Morales et al., 2010) profuse production of root exudates (Gomathy et al., 2018), more quantity of carotenoids and volatile compounds (Bona et al., 2017), enhanced accumulation of anthocyanins, chlorophyll (Balsam et al., 2011) and increased level of sugars, organic acids, vitamin C, flavonoids, and minerals (Zeng et al., 2014). AM fungi inoculated cucumber plants showed resistant to soil borne pathogens alleviate salt stress and overcome chill temperature (Aljawasim et al., 2020).

Plant growth promoting yeast can be act as a potential biological agents in different sectors of sustainable farming (Mukherjee et al., 2020) The potential use of yeast starts from baking, fermentation *etc.* and its vital role in agriculture (Barnett and Barnett, 2011) is gaining momentum nowadays and the interest of yeast in agriculture is increasing spontaneously. PGPY is widely used as biocontrol agents towards control of many diseases of crop plants (Pimenta et al., 2010). They are very well known to have the ability to solubilize phosphorus (Amprayn et al., 2012), offered resistance to stress (El-Zohri et al., 2017) and promote the growth and yield of plant as a potential biological agent (Hesham and Mohamed, 2011). Yeasts produces copious amount of plant growth promoting enzymes, IAA, GA and cell wall degrading enzymes that retard the growth of plant pathogens (Fu et al., 2016). Yeast has also been employed for the degradation of pesticides from the different sources (Han et al., 2019) reported that *Clavispora lusitaniae* showed pendimethalin degradation in CMB liquid culture (74% of 200 mg L^{-1}). Even the renowned baking yeast *Saccharomyces cerevisiae* has been employed for plant growth promotion and biocontrol agent in adverse conditions (Amprayn et al., 2012; Ibrahim and El-FikiI, 2019; Ferraz et al., 2019) reported that cacao witches broom disease was efficiently controlled by yeast.

Williopsis saturninus is endophytic yeast obtained from the maize roots and proven to produce indole-3-acetic acid (IAA) and indole-3- pyruvic acid (IPYA) (Nassar et al., 2005). Cytokinins are vital hormones that promotes plant growth and one among them is zeatin, reported to be synthesized from yeast *Sporobolomyces roseus* and *Aureobasidium pullulans* isolated from the rhizosphere soil of plants (Streletskii et al., 2019; Hesham et al., 2017, 2018) reported that *R. mucilaginosa, C. albidus,*

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P. membranifaciens, H. uvarum and *C. alifornica* had the ability to kill pathogens and the *Rhodotorula* species such as *R. lactose, R. nymphaeae, R. graminis, R. slooffiae* degrade the petroleum compounds from the soil through direct and indirect mechanisms. Even the crop residues can easily be degraded to enrich the soil *via* cellulose degrading enzymes of *S. cerevisiae* (Bae et al., 2015). Different genus and species of yeast can be explored further for various beneficial activities to serve as potential biological agents.

Influence of AM fungi and PGPY in nutrient uptake

AM Fungi colonization promotes nutrient uptake in plants. It is proved that AMF can improve the amount of macro and micronutrients significantly, which leads to increase in biomass production (Chen et al., 2017; Mitra et al., 2020). AM fungi can maintain approximately 90% of the plant's phosphorus, 60% of nitrogen and 20% of carbon (Smith et al., 2008). The level and the quantity of nitrogen, phosphorus, calcium and other nutrients like sulphur, potassium, iron, copper, manganese and zinc in plants can be increased by using AM fungi (Cao et al., 2015; Mustafa et al., 2016; Mei et al., 2019; Khan et al., 2021). The ability of *Rhizobium* to fix Nitrogen may be enhanced if the host plant is also in symbiosis with AM fungi. In this case, *Rhizobium* and AM fungi synergistically work together to increase the rate of colonization, inorganic nutrient uptake and plant development (Harrison, 1999). Legume crops are preferred to make symbiosis with AM Fungi as these symbionts are more helpful to supply P. This can be very helpful to the legume plants under the nutrient deficit conditions. Each and every AM fungal species are unique in formation of nodules that ultimately helps and improves Nitrogen fixation (Ibijbijen et al., 1996; Gomathy et al., 2021). AMF ensures the plant to get essential nutrients, provide mineral nutrients like nitrogen, phosphorus, potassium, calcium, zinc and sulphur. AMF give nutritional support to the plants even in unfavourable conditions. AMF produce arbuscules which is helpful in exchange of inorganic minerals, carbon and phosporus (Li et al., 2016; Prasad et al., 2017). Absorption of minerals and water from the faraway places are possible for AM fungi through the hyphae that are very thin when compared to root hair. By using the fungal hyphae they will penetrate even very small tiny pores of the soil (Allen et al., 2011). Micronutrients like zinc, copper, iron and manganese can also be absorbed by the AMF under nutrient deficient areas (Canton et al., 2016; Liu et al., 2018). By using the fungal hyphae AMF can expand the fungal network to the nutrient deficient areas, which helps the plant to penetrate larger volume of soil.

Plant growth can also be increased by inoculating the crops with yeast that solubilize the nutrients, produce different phytohormones, enzymes that can be helpful for plant growth (Amprayn et al., 2012; Silambarasan et al., 2019; Kumla et al., 2020). Phosphorus is a mineral that is tightly bound with other chemical cations and the availability of P is very less. The application of gibbrellic acid with yeast will improve the nutrient uptake of crop plants (Youssef et al., 2022). *Lachancea thermotolerans* is the yeast species which has more P solubilizing capacity, *Saccharomyces spp.* and *Hanseniaspora uvarum* strains contain more phosphate solubilizing capacity (Fernandez et al., 2020). Yeast can provide nutrients and helpful for nitrogen fixation, phosphorus and potassium solubilization and release trace elements like iron and zinc. Yeast produces phytohormones like auxins, cytokinins and gibbrelins which can promote the growth of plants (Hernández et al., 2021). *Candida tropicalis* is the yeast which is

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isolated from soil which fixes nitrogen and also solubilizes phosphorus (Mukherjee et al., 2015). *Torulaspora globosais* can solubilize K from the ultramafic alkaline rock (Rosa et al., 2012).

AM Fungi and PGPY in biotic and abiotic stress management

Biotic stress

Plant pathogen

AM fungi improve the plant defence mechanism and provide more ability to get resistant against pests and pathogens (Begum et al., 2019). Plant pathogens are more prevalent in the root area of the crop plants which can trigger the plants against the pathogens by releasing some phenolic compounds which can reduce the pathogen growth. AM fungi confer the plants with more resistance that develop physical barrier and reduce the spread of pathogens (Nanjundappa et al., 2019; George et al., 2023). Plants obtain their nutrients mostly via the joint activity of their roots and the microorganisms that are associated with them. These microbes are important for both suppressing soil pathogens, mobilizing and absorbing nutrients (Ismail et al., 2013). *Rhizophagus irregularisis* reduces the disease in tomato caused by *Candidatus Liberibacter solanacearum.* AM fungi not only reduce the infestation caused by fungi but also protect the plants from nematode infestation caused by *Meloidogyne incognita* in coffee. *Fusarium oxygensporum* f. sp. *Lycopersici* is the soil borne fungus which causes wilt disease in tomato which can reduces the yield (Akköprü and Demir, 2005; FAOSTAT, 2019).

Yeast has an ability to control the pathogenic microorganisms and increases the tolerance of the plant against pathogens (Kamel et al., 2016; Ibrahim and El-FikiI, 2019). Yeast has various antagonistic properties, that is helpful to know that their mode of action against the pathogen and increase their viability (Parafati et al., 2016). Usually, yeast has the ability to grow faster and form biofilms on the outer surface of the spoiled fruit. Due to formation of biofilms competition for nutrients occur between the pathogen and yeast. Yeast uses all the nutrients due to deficiency of nutrients the pathogenic spore germination is reduced. *Aureobasidium pullulans* increases the competition of nutrients to the pathogen *Penicillium expansum* (Bencheqroun et al., 2007), *Rhodotorula glutinis* also control the plant *pathogen Penicillium expansum* by developing siderospores (Calvente et al., 1999). Yeast not only prevent plants from pathogen attack by creating a competition for space and nutrients but also by producing volatile organic compounds (VOCs) that has parasitic effect on plant pathogens. The parasitic effect of yeast produced VOCs on plant pathogens is a multifaceted mechanism involving direct inhibition, priming of plant defenses, and disruption of pathogen behavior. Yeast produces volatile compounds during their primary and secondary metabolism (Korpi et al., 2009). The mixtures of volatiles called volatilome. VOC include alcohols, aldehydes, cyclohexanes, benzene derivatives, heterocyclic compounds, hydrocarbons, ketones, phenols, thioalcohols and thioesters. Physical contact is not needed between pathogen and VOC (Huang et al., 2012; Parafati et al., 2017). Genus *Hanseniaspora* prevents the plants from *Botrytis cinerea* by releasing VOCs (Ruiz-Moyano et al., 2020). Volatile organic compounds and glycoproteins produced by yeast disrupt the cell wall of pathogens and acts as a biocontrol agent (Freimoser et al., 2019). *Rhizoctonia solani* is a soil borne fungal pathogen which can

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cause severe problem in root structure it can be prevented by yeast *Rhodotorula glutinis, Candida valida and Trichosporon asahii* (El-Tarabily, 2004). Another pathogen control mechanism is parasitism, which is directly intract between yeast and pathogen. Yeast secrete lytic enzyme and develop upon the pathogenic fungi which causes death of pathogens. To control *Colletotrichum gloeosporioides*, the yeast *Candida famata, Rhodotorula mucilaginosa* use β-1,3-glucanase enzyme it causes parasitic effect on pathogens (Magallon-Andalon et al., 2012; Lima et al., 2013). Different genus and species of yeasts which suppress the plant pathogens are given in *Table 2*.

Table 2. *Application of yeast against Plant pathogen*

Yeast	Plant pathogen	References
A. pullulans	*F. culmorum*	Wachowska and Głowacka. (2014)
Saccharomyces cerevisiae	*Penicillium expansum*	Scherm et al. (2003)
Candida famata	*Colletotrichum gloeosporioides*	Magallon et al. (2012)
C. oleophila	*P. expansum, B. cinerea*	Jolanta Kowalska et al. (2022)
Cystofilobasidium infirmominiatum	*Penicillium italicum*	Vero et al. (2013)
M. pulcherrima	*B. cinerea*	Mondino et al. (2012)
M. fructicola	*B. cinerea, Monilinia spp.*	Jolanta Kowalska et al. (2022)
Aureobasidium pullulans	*Penicillium expansum*	Vero et al. (2013)
Candida oleophila	*Botrytis and Penicillium*	Ballet et al. (2015); Sebastien and Jijakli (2014); Mondino et al. (2012)

Insects

There are number of studies stating role of yeast in insecticidal activity. Combined inoculation *of Cydia pomonella granulo virus* and yeasts like *M. pulcherrima*, *Cryptococcus tephrensis* or *Aerobasidium pullulans* increase the death rate of larva of apple moth larval infestation (Knight and Witzgall, 2013). Sex pheromone for *Helicoverpa armigera* was prepared by the fermentation *of Yarrowia lipolytica* yeast that can be used as pheromone trap (Holkenbrink et al., 2020).

Abiotic stress

Drought

Drought reduces the plant yield and causes a severe stress among the crop plants (Posta et al., 2020). It causes harmful effects on growth of the plant by disturbing the activity of enzymes, ion uptake and assimilation of nutrients (Ahanger et al., 2017). Due to reduction of water the stomatal function will affect photosynthesis which decreases the yield of the crops (Osakabe et al., 2014). AM fungi can tolerate the drought and enhance water uptake (Posta et al., 2020). AMF produces larger volume of extraradicle hyphae which can helpful to tolerate the drought stress as water requirement of crop plants can be met out ever from the distant places (Gianinazzi et al., 2010). Another response of plant to mitigate stress is production of phytohormones. The balance of hormones controls plant's ability to withstand abiotic stress. The most basic signaling hormone during stress is abscisic acid (ABA), which affects root hydraulic conductivity,

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transpiration rate and aquaporin expression (Ouledali et al., 2019). ABA reduces the water loss by closure of stomata. AM fungi inoculation will efficiently control the stomata by regulating the level of ABA (De Ollas and Dodd 2016; Ouledali et al., 2019). Some other phytohormones also play an important role in water stress are strigolactone and auxin (Mostofa et al., 2018). AM fungi enhance these phytohormones in response to drought stress (Ruiz-Lozano et al., 2016). AM Fungal species like *Rhizophagus irregularis*, *F. mosseae*, and *R. fasciculatus* give major response against drought stress in crops like maize, tomato and wheat (Allen et al., 1983; Bárzana et al., 2012; Chitarra et al., 2016). Influence of AMF against drought stress in various agricultural and horticultural crops such as sorghum, wheat, chilli, tomato, onion etc. along with the mechanism are given in *Table 3*.

Salinity

Salinity of the soil increases major problem in food security as salinity stress will reduce the plant development in the vegetative stage and also reduce yield. AM fungi are helpful for plants to tolerate salinity and increase the productivity (Talaat and Shawky, 2014; Abdel Latef and Chaoxing, 2014). AM fungi can also help to produce jasmonic acid, salicylic acid and some other inorganic acids (Hashem et al., 2018) in some crops like maize, wheat and tomato will tolerate against salinity stress with the inoculation of *R. irregularis*, *F. mosseae*, and *R. fasciculatus* (Daei et al., 2009; Hajiboland et al., 2009; Estrada et al., 2013). In *Antirrhinum majus* plants AM fungi increase the water potential and water use efficiency in salt stress conditions (El-Nashar, 2017).

Heavy metals

Mining sites and polluted sites with heavy metals contain AM fungi that are specifically adapted to soil pollution by heavy metals (Hildebrandt et al., 2007; Wang, 2017). Ecotypes are the AM fungi isolates which is mostly live in mine areas that highly polluted with heavy metals which has ability to withstand heavy metals depending on internal and external factors (Gildon and Tinker, 1981; Leyval et al., 1997; Joner and Leyval, 1997; Smith and Read, 2008). AM fungi retain the metal in the mycorrhizal plant roots and improve shoot biomass by restricting translocation to the aerial parts (Janeeshma and Puthur, 2020). Inoculation with AM fungi showed the best results in terms of percentage of seed germination, sustainability of seedlings, fresh weight and dry weight of plants. In two different heavy metal polluted soils, root colonization of maize plants with *Glomus* isolates reduced heavy metal concentrations in shoots and roots, and increased the contents of essential elements like K, P, and Mg in roots (Kaldorf et al., 1999). Bioremediation of heavy metal is done by hyphal “metal binding” which decreases the availability of elements like Cu, Pb, Co, Cd, and Zn (Audet and Charest, 2007). Response of AM fungi on Plant stress is given in *Figure 1*.

Role of AM fungi and yeast in crop productivity

The effect of climate change on agricultural yield has posed a danger to global food security. Climate change such as increase in temperature, altered rainfall pattern, extreme weather that exaberate soil erosion, runoff cause adverse effect in crop production (Ahmed et al., 2015; Van der Linden and Goldberg, 2020).

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Table 3. *Influence of AMF against drought stress*

Crop	AMF	Response of AMF to drought stress condition	Reference
Sorghum	*R. irregularis*	Improved uptake of N^{15}	Symanczik et al. (2018)
Pistachio	*G. etunicatum*	Enhanced nutrient concentrations (P, N, K, Ca, Fe, Zn, and Cu), total chlorophyll, leaf area, proline content, flavonoids contents, CAT and POD activities soluble sugar, soluble proteins contents, shoot and root wt.	Abbaspour et al. (2012)
Wheat	*R. intraradices, F. mosseae, F. geosporum*	Increase in Relative Water Content	Mathur et al. (2018)
Lavender	*R. irregularis F. mossea*	Drecrease in antioxidant compounds like (glutathione, ascorbate and H2O2) Increase in N, K content, water content, biomass	Marulanda et al. (2007)
Wheat	*F. geosporum*	Stimulation of nutrient and water uptake	Ibrahim et al. (2011)
Chilli, Tomato	*Rhizophagusfasciculatus Rhizophagusirregularis*	Increased chlorophyll contents, , root length biomass, shoot length, and reduced proline content	Beltrano et al. (2013); Hajiboland et al. (2009)
Wheat	*G. claroideum*	Increased chlorophyll content and total dry weight	Beltrano et al. (2008)
Tomato, Corn	*Rhizophagusirregularis*	Increased in rate of apoplastic water flow	Bárzana et al. (2012)
Onion	*Glomus etunicatus*	Increased phosphorus content, fresh and dry wt.	Nelsen and Safir (1982)
Tomato	*Rhizophagusirregularis*	Increase in primary branches, plant height, fruit yields, shoot and root dry matter, , number of flowers and fruits, leaf relative water content (RWC), quality of fruits (less acidity and quantities of ascorbic acid and total soluble solids),N and P contents water use efficiency (WUE)	Subramanian et al. (2006)
White clover	*R. irregularis*	Increased nutrients content (P, K, Ca, Mg, Zn and B),glutathione reductase activity, proline concentrations, dry weight, relative water content	Ortiz et al. (2015)
Wheat	*R. fasciculatus F. mosseae*	Increased leaf osmotic adjustment and stomatal conductance	Allen et al. (1983)
Tomato	*F. mosseae R. irregularis*	Increased proline concentrations, stomatal density, plant height and biomass, , capacity to absorb CO2, intrinsic water use efficiency (iWUE) index,and reduction in leaf and root ABA contents, hydrogen peroxide	Chitarra et al. (2016)
Barley	*Glomus intraradices*	Increased activity of phosphatase enzyme, , Phosphorus content root volume and phosphatase enzyme activity	Bayani et al. (2015)
Soyabean	*AMF*	Incerased leaf area index, leaf proline, relative growth rate, photosynthesis rate, fresh weight and dry weight of seeds	Pavithra and Yapa (2018)
Sweet potato	*Glomus spp*	Enhanced soluble sugars, Proline adjustment in osmotic potential	Yooyongwech et al. (2016)

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Crop	AMF	Response of AMF to drought stress condition	Reference
Trifoliate orange	*Funneliformismosseae, Paraglomusoccultum*	Increased hyphal water absorption rate, leaf water potential and hyphal length	Zhang et al. (2018)
Durum wheat	*Rhizophagusintraradices*	Increase in grain biomass and copper, iron, manganese, zinc and gliadins contents in grains	Goicoechea et al. (2016)
Geranium	*Rhizophagusintraradices, Funneliformismosseae*	Enhanced plant biomass, essential oil content, nutrient content, glomalin related soil proteins , plant biomass, and essential oil content	Amiri et al. (2015)
Bambara groundnut	*Glomus intraradices, Gigasporagregaria, Scutellosporagregaria*	Enhanced soluble sugars, mineral content, acid phosphatase, reduction proline content	Tsoata et al. (2015)
Snapdragon	*Glomus deserticola*	Increased leaf area, shoot length, shoot and root diameter, water content, leaf number per plant, Proline and chlorophyll	Asrar et al. (2012)
Black locust (pea)	*Funneliformismosseae and Rhizophagusintraradices*	Enhanced net photosynthetic rate and dry biomass, water use efficiency.	Yang et al. (2014)
Lettuce and tomato	*Rhizophagusirregularis, Glomus intraradices*	Enhanced biomass production, ABA accumulation and synthesis, strigolactone production efficiency of photosystem II	Ruiz-Lozano et al. (2016)
Hardy sugarcane	*Glomus spp.*	Enhanced antioxidant enzymes, levels of metabolites, phenolics, glutathione, ascorbic acid, chlorophyll fluorescence, leaf water uptake, levels of metabolites and plant biomass	Mirshad and Puthur (2016)
Wheat	*Glomus mosseae*	Enhanced osmotic potential, chlorophyll content and fluorescence, activities of antioxidant enzymes, ascorbic acid, enzymes of N and P metabolism, and contents of N, P, and K	Rani et al. (2018)
Pangola grass	*Rhizophagusirregularis*	Enhanced stomatal conductance, peroxidation, shoot dry matter, lipid, H_2O_2 in shoot and root	Pedranzani et al. (2016)
Strawberry	*F. mosseae BEG25, F. geosporus BEG11*	Increase in WUE, plant survival, shoot and root fresh weights	Boyer et al. (2016)
Wheat	*Glomus mosseae, Glomus fasciculatum, Gigasporadecipiens*	Increase in total chlorophyll pigments and other plant growth parameters	Pal and Pandey. (2016)

To mitigate this problem Arbuscular Mycorrhizal Fungi is helpful in agriculture as it plays a crucial role in mitigating the impacts of climate change on agriculture, particularly through their influence on phosphorus cycling and availability. Arbuscular Mycorrhizal fungi enhances phosphorus uptake, reduces the need for chemical fertilizers, improves soil carbon sequestration and increases plant resilience to climate stress. In tropical soils, Arbuscular Mycorrhizal fungi play an important role as phosphorus content is very less in tropical soils (Adisa et al., 2019). AMF consume only 25% of phosphorus another 75% of phosphorus will be utilized by the plants. AMF and plant symbiosis play an important role in crop productivity and ecosystem functioning. They are the key importance for sustainable crop development (Gianinazzi et al., 2010).

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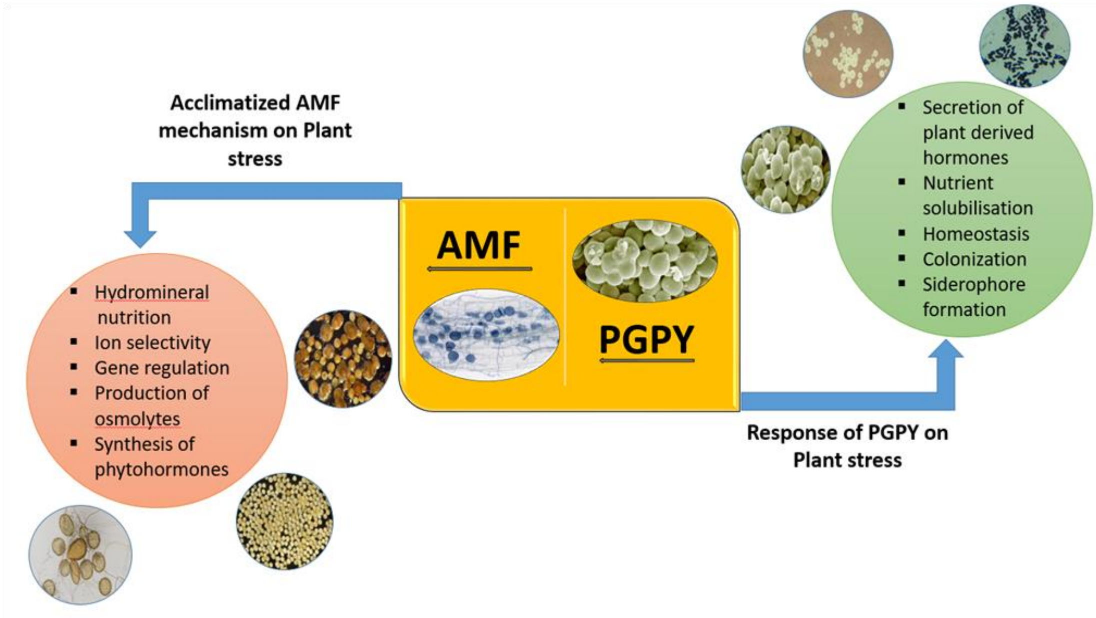

Figure 1. *Response of AM fungi on plant stress*

Arbuscular mycorrhizal fungi is helpful in vast production of maize (Sabia et al., 2015), elephant foot yam (Lu et al., 2015) and potato (Hijri, 2016). It has the greater potential for improving the crop production and also improves the synthesis of phytochemicals in food crops and prepares them good for consumption (Sbrana et al., 2014; Rouphael et al., 2015). In tomato *Fusarium oxysporum f. sp. Lycopersici* is the disease causing pathogen which affects the plants, by using AMF it can produce antimicrobial properties and restrict the mycelial development of the pathogen. Reduced disease incidence may increase the growth of the crops, biomass, nitrogen, phosphorus, and potassium content, and productivity of the crop (Kumari et al., 2019). AMF can improve soil physical characteristics such as available nutrients in soil, water retention capacity, activity of microorganisms in soil, C, N, P cycle by the improvement of soil characteristics it is helpful for enhancing the production and productivity of the crop plants (Sadhana, 2014; Jamiołkowska et al., 2018; Parihar et al., 2020). Combined inoculation of AMF and nitrogen fixing bacteria will increase the nodulation potential, fixation of Nitrogen and plant productivity (Herrera et al., 1993). In agroforestry crops, *Schizolobium parahyba* is inoculated with AMF and PGPR will improve the quality of wood and increase the weight of wood by 20% when compare to the inorganic fertilizers (Blake, 1919). AMF also give major impact on the crops under salinity stress conditions, inoculation of AMF will improve the growth rate and productivity of crops under saline conditions (Talaat and Shawky, 2014; Abdel Latef and Chaoxing, 2014; El-Nashar, 2017).

Reduction in Nitrogen level will cause severe decrease in crop productivity to mitigate this problem yeast can be helpful for increasing the nutrient availability to the crop plants (Leghari et al., 2016). Yeast mixed with biofertilizers will improve the plant weight, dry matter, grain and straw yield of the rice crop (El-Sirafy et al., 2011). Which increases the productivity in marigold crops the foliar application of yeast will enhance the plant growth and productivity (Taha et al., 2020). In various crops *Saccharomyces cerevisiae* increases the plant growth and productivity characteristics (Al-Maeini and

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Al-Isawi, 2017) spraying of yeast extract hives the high weight of seeds. Foliar application of yeast may increases the plant growth stimulants, like gibberellins, auxins, and cytokines, which promote cell division and growth. The primary effect of foliar yeast spray may be that yeast increases nutrient mineral absorption through overall improvement (Ahmed et al., 2023). Efficiency of Arbuscular mycorrhyzal fungi and Plant growth promoting yeast on crop productivity is given in *Figure 2*.

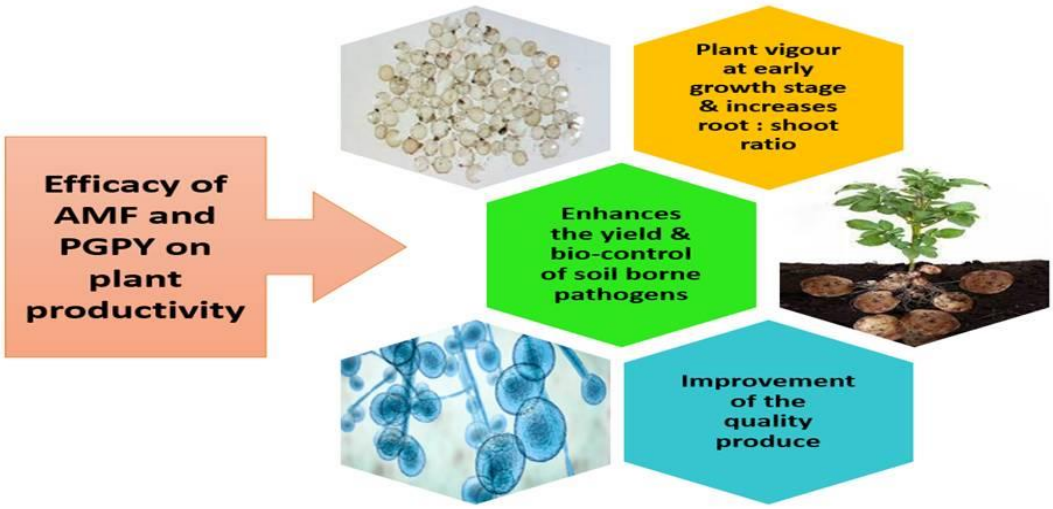

Figure 2. *Efficiency of Arbuscular mycorrhyzal fungi and Plant growth promoting yeast on crop productivity*

Interaction with other biofertilizer

Most of the biofertilizers will interact with AM fungi. Some of the strains of *Rhizobium* will combinely inoculated with AM fungi which will improves the Nitrogen content, increases the number of root nodules and rate of mycorrhizal infection. This type of symbiosis will give positive effect in Legume crops (Razakatiana et al., 2020). AM fungi also favours the legume crops for their nodulation under some extreme conditions like low fertility (Razakatiana et al., 2020), flood and drought conditions (Hao et al., 2019). The fungal biocontrol agent like *Trichoderma viride* and AM fungi is combinely helps in improving the growth parameters, chlorophyll and carotenoid contents (Metwally et al., 2020). Phosphate solubilizing bacteria like *P. fluorescence* and *B. megaterium* are inoculated with AM fungi which will improve the solubilization of phosphate which helps to increase productivity. Agroforestry crops like Eucalyptus will be inoculated by AM Fungi and beneficial microbes will improve the quality of seedlings by improving the biomass and in matured plants it will increases the wood quality (Karthikeyan and Prakash, 2008).

Endophytic yeast increases the nod factor when inoculate with *Rhizobium sp* in legume crops (Geetha et al., 2020). Yeast like *Saccharomyces cerevisiae* will increases the formation of nodules, length and dryweight of the crop plants when inoculated with *Rhizobium trifolii* (Tuladhar and Rao, 1985). Interaction of *Bacillus megaterium* with yeast will increase the concentration of available phosphorus in soil (Abdul-Hassein and Hassan, 2021), these types of interaction is cost effective and ecofriendly (Karthikeyan and Prakash, 2008).

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Conclusion

This review focused on favorable effect of AM fungi and plant growth promoting yeast on crop plants as potential biological agents, role in uptake of nutrients, increasing crop productivity and tolerates biotic and abiotic stress conditions. AMF treated plants have double the amount of biomass compared to the control plants. Compared to control plants, plant growth promoting yeast produces two-fold times of antioxidant enzymes that help the plants to overcome biotic and abiotic stress. Nowadays there is an increase in chemical fertilizers and pesticides which increases hazardous damage to the environment. To mitigate this problem AM fungi and PGPY can be effectively and efficiently used. Recent studies concluded that AM fungi and PGPY is more helpful in nutrient uptake, mobilization of nutrients, soil health, bioremediation, pests and disease management. Co inoculation of yeast and AM fungi play some specific role in plant development, reduction in usage of chemical fertilizers and pesticides, which ultimately results in sustainable agriculture.

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