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Fungal and bacterial endophytes for rice improvement with special reference to drought stress

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Abstract
Rice (*Oryza sativa* L.) ranks number one regarding its production and area under cultivation. Abiotic factors result in 50% losses each year in rice crop. Major abiotic stressors like drought, salinity, nutrition and heat stress are controlled by several genes and can't be controlled by improved agronomic practices and/or inserting one or two genes in the plants. Endophytes, primarily residing in the tissues of the host plant, can be useful in sustai'[[nable agriculture owing to various features they add to the plants. Though recent researches have documented pathogenic activity of endophytes but mutualistic, non-pathogenic, and/or useful aspects are more prominent. So, only the beneficial aspects of the endophytes will be discussed here. Though naturally occurring and mostly isolated endophytes from plant tissues are usually fungi, but endophytes are not limited to fungi only many bacterial species have also been documented as endophytes and in some cases they prove more beneficial than fungal endophytes. Till date there was no any recent review on the use of bacterial and fungal endophytes in increasing plant tolerance to the abiotic stressors. So, this review has given a recent update on role of endophytes in improving rice plant (s). This review will help researchers and scientists to screen the most promising endophytes in field and their application for the betterment of farmers.

Keywords: Abiotic stressors; Plant growth; drought conditions; Physiological changes; Phytochemicals

Introduction

Rice (*Oryza sativa* L.) ranks number one in the world regarding annual production of 700 million tons and total area under cultivation is 158 million hectares. It is cultivated in more than a hundred countries. Asia accounts for 90% of world rice production i.e. 640 million tons. However, other continents like Africa, Americas, Australia and some parts of Europe also have minor contribution in rice production (Prasad et al., 2017; Behzad et al., 2019). The area under cultivation of rice is decreasing each year owing to increasing population pressure, high soil toxicity, lack of irrigation water and urbanization during recent decades (Gilani et al., 2019). However, in majority of areas ideal yield can't be achieved. Rice growth and hence yield is affected by abiotic and biotic stressors. However, biotic factors can be managed easily by different control strategies. While, abiotic stress factors can result in various changes in physiology, morphology and biochemical properties of rice plant which in turn decrease the quality and quantity of yield in rice crop (Pandey et al., 2017). They are capable of decreasing rice yield upto 50% resulting in high financial losses (Vij and Tyagi, 2007; He at al. 2020). Environmental circumstances that restrict growth and production below optimum levels are referred to as abiotic stress. Abiotic stress responses in plants are complex and dynamic (Skirycz et al. 2010; Cramer 2010; Arruda and Barreto, 2020). Drought and high temperatures are two major abiotic variables (Bamisile et al. 2018). Drought stress is placed on rice crops when the plant does not receive enough moisture to complete its life cycle. Furthermore, agricultural dryness promotes biomass accumulation (Polania et al. 2020; Tiwari et al. 2020). Water deficiency slows plant growth by lowering water intake into growing cells and altering the rheological characteristics of the cell wall enzymatically; for example, ROS (reactive oxygen species) activity on cell wall enzymes (Skirycz et al. 2010; Lee et al. 2019; Zhang et al. 2020). Furthermore, a lack of water changes the cell wall in nonenzymatic ways, such as through the interaction of pectate and calcium (Vaahtera et al. 2019; Wang et al. 2019). The controlled ion influx and efflux at the plasma membrane, as well as vacuolar ion sequestration, deal with the salinity-induced imbalance of cellular ion homeostasis (Dourmap et al. 2020). Drought and salinity have significant negative effects on cellular energy supply and redox homeostasis, which are counterbalanced by global reprogramming of plant primary metabolism and changes in cellular architecture. (Guan et al., 2010; Vaahtera et al. 2019; Wang et al. 2019).

Plants with high abiotic stress tolerance have complex multicomponent signalling networks. Due to the presence of a variety of complicated pathways and genes involved, conventional techniques of enhancing plant tolerance to stress, such as agronomic measures or the breeding of resistant cultivars, can be time consuming and unreliable. Because seeds serve as generative organs in the regeneration and dispersion of blooming plants, endophytic colonisation at the seed is crucial (Shuba et al. 2019; Kumar et al. 2020). Furthermore, the importance of mycobionts as potential seedling recruitment drivers in natural, disturbed, and contaminated ecosystems cannot be overstated (Ripa et al. 2019; Fan et al. 2020). Fungal endophytes and bacterial endophytes are the two types of endophytes that exist. Seed germination can be improved and plants can be protected from environmental stressors by using endophytic symbionts (Vujanovic et al. 2019). (Waller et al. 2005). In both ideal and severe climatic conditions, seed germination is a critical phenophase for plant survival and reproduction. As a result, creating ways to improve and anticipate seedling emergence in the face of heat or drought is important. To describe this type of plant mycosymbiosis, Vujanovic and Vujanovic (2007) established the term "mycovitality." In host plants, endophytic fungi are common and varied. Every plant examined so far has at least one species of endophytic fungus, and many plants, particularly woody plants, may have hundreds or thousands (Gaylord et al., 1996; Faeth and Hammon, 1997; Saikkonen et al., 1998; Arnold et al., 2000). Fungi and other microorganisms (bacteria, yeast) on plant leaf and root surfaces, rhizosphere, and interior tissues influence plant performance in natural habitats. In other words, they can boost a plant's ability to withstand abiotic stress once it has passed the seedling stage (Shuba et al. 2019; Kumar et al. 2020). Bacterial endophytes have been linked to biotic and abiotic stress in the same way (Hardoim et al. 2008; Santoyo et al. 2016).Various research studies have demonstrated the importance of bacterial and fungal endophytes. However, no current evaluation of the role of endophytes in rice improvement has been published. As a result, this review is created with the importance of endophytes in mind, as well as their role in rice improvement. This latest review will aid researchers in gaining a better understanding of endophytes for rice enhancement and their application in the field.

Drought stress

Nonirrigated lands produce over half of the world's rice (Oryza sativa L.), but only 1/4th of overall rice output (Cogay et al., 2020). Rice is particularly vulnerable to water shortages during the reproductive phase of growth, when even a minor exposure to the stress can result in a significant loss in grain yield (Melandri et al. 2020). Drought in rice can have morphological, physiological, molecular, and phytochemical consequences, as well as a negative impact on plant mineral nutrient intake due to endophyte inoculation (Farooq et al., 2009).

Uses of different endophytes in differents plants

Stress	Endophytes	Plant	Isolation from	Plant gene induced	Outcome	Referances
Drought	Sinorhizobium meliloti	Medicago sativa	Root nodules	Superoxide dismutase genes (sod)	FeSOD and CU/ZnSOD are upregulated	Naya et al. (2007)
	Trichoderma hamatum DIS 219b	Theobroma cacao	Roots	DREB2A, CBL1, ANAC072 and RD29A, ERD1 were upregulated	Drought-induced stomatal conductance and net photosynthesis alterations are	Bae et al. (2009)

					delayed.	
	Piriformospora indica	Brassica campestris ssp. chinensis	Roots	DREB2A, CBL1, ANAC072 and RD29A were upregulated	Peroxidases, catalases, and superoxide dismutases levels have increased.	Sun et al. (2010)
	Gluconacetobacter diazotrophicus	Saccharum officinarum cv. SP70-1143	Shoot	Upregulation of ERD15 DREB1A/CBF3 and DREB1B/CBF	IAA and proline production	Vargas et al. (2014)
	Trichoderma harzianum TH-56	Oryza sativa	Roots	DHN/AQU	Upregulation of aquaporin, dehydrin and malonialdehyde genes	Pandey et al. (2016)
Stress	Pseudomonas pseudoalcaligenes along with Bacillus pumilus	Rice	Roots	gbsA and gbsB	Accumulation of glycine betaine like compounds, decline in proline content by 5%	Jha et al. (2011)
	Achromobacter xylosoxidans UM54	Salt-sensitive rice GJ-17	Roots	sod1 downregulated	Reduced lipid peroxidation and superoxide dismutase activity	Jha and Subramanian (2014)
	Pantoea agglomerans	Zea mays mexicana	Roots	zmPIP genes are upregulated	Upregulation of aquaporins	Gond et al. (2015)
	P. indica	O. sativa	Roots	PiHOG1 upregulated	Increased glycerol concentration	Jogawat et al. (2016)
	P. pseudoalcaligenes	Arabidopsis thaliana	Roots	HKT1, KAT1, KAT2 coda (choline dehydrogenase) upregulated	Regulation of Na^+ and K^+ homeostasis	Abdelaziz et al. (2017)
Osm	P.	Capsi	Root	CaACCO	Gene encodes the	Szideri

otic stress	indica	cum annum	s and leaves	CaLTPI	enzyme ACC oxidase Encodes a lipid transfer protein	cs et al. (2007)
	Pseudomonas sp.	Epacrids, Nicotiana tobaccum and A. thaliana	Roots	SEX1	Genes for the starch-degrading enzyme, glucan-water dikinase	Sarma et al. (2011)
Temprature Cold	Burkholderia phytofirmans PsJN	A. thaliana	Roots	Downregulation of RbcL and COR78	Accumulation of pigments and induced cold response pathway	Su et al. (2015)
	Pseudomonas vancouverensis OB155-gfp Pseudomonas frederiksbergensis OS 261-gfp	Solanum Lycopersicum	Seeds	Upregulation of CBFs, COR15a and COR78 LeCBF1, LeCBF3 and TomLOX gene expression	Codes for proteins that protect cells against cold/chilling stress. Reduced membrane damage and reactive oxygen species level. Tomato lipoxynase	Subramanian et al. (2015)
Heavy metals: Cd	Neotyphodium uncinatum	Perennial ryegrass	Roots	——	Enhanced tillering and reduced leaf elongation	Ren et al. (2006)
As	Staphylococcus arlettae	Brassica juncea	Roots	arsC gene	Arsenic reductase activity. Increased soil dehydrogenase, phosphatase and available phosphorus	Srivastava et al. (2013)
Zn Cd As and Pb	Pseudomonas koreensis AGB-1	Miscanthus sinensis	Roots	——	Extracellular sequestration of Zn, Cd, As, and Pb boosted Catalase and SOD activity in plants by 42 and 33 percent, respectively.	Babu et al. (2015)
Nutrient	Bacillus sp. and Lys	Prosopis strom	Roots	——	Low lipid peroxidation, antioxidant enzyme activity, and	Sgroy et al. (2009)

	inibacillus sp.	bulifera			photosynthetic pigments IAA, Gibberellic acid, Siderophore	
	Pseudomonas sp.	Pisum sativum	Seeds	gcd genes upregulated	Gluconic acid used by bacteria to solubilize phosphate	Oteino et al. (2015)

Morphological effect of drought tolerant endophytes

Growth, moisture status, and photosynthetic efficiency of two maize cultivars were measured by Naveed et al. (2014). For this purpose, two bacterial endophytes viz. *Enterobacter* sp. and FD17 *Burkholderia phytofirmans* strain PsJN were used to infect two maize cultivars grown under drought stress conditions. In this experiment, drought stress was imposed on the test plants during the vegetative growth stage after 45 days of plants. After successful inoculation, endophytic bacterial strains were detected in leaves, shoots, and roots of all the test plants. The long-lasting effect of drought stress was observed on different parameters of maize seedlings like leaf moisture, growth, and photosynthetic efficiency. Effects of drought exposure on maize were decreased by inoculation of endophytes leading to increased leaf area, root biomass, shoot biomass, chlorophyll contents, photosynthetic rate, and photochemical efficiency. Additionally, higher leaf moisture contents were observed in the treated plants than the control. Less leaf damage (relative membrane permeability) was found in infected plants. Regarding growth and other parameters in tested plants, strain PsJN was found more effective than FD17, under drought stress. Concluding, different strains of endophytes can give a different level of protection against drought stress in different plant genotypes.

According to Rudgers and Swafford (2009), it is difficult to guess from natural symbionts whether they help plants in adapting them to stress conditions or not. They studied the mutualistic relation of an inoculated endophytic fungus with a grass species, against drought stress. This experiment was conducted under controlled conditions where plants inoculated with fungi (*Epichloë elymi*) were kept under drought and normal conditions. Plants kept under drought conditions were subjected to 67% less water, about the dry areas of the Midwestern US which face approximately this level of drought stress, where *E. virginicus* is common. Unlike the prospects, the grass *E. virginicus* performed better under normal conditions in the presence of endophytethan as compared to the conditions under drought stress. Biomass increased by 45% in the infected plants than naturally uninfected plants under water sufficient conditions and 23% more under water deficit conditions. Both root biomass and the number of tillers increased by an infection in endophyte-infected plants. The difference regarding root biomass and the number of tillers was also observed under normal and water scarce conditions. However, the presence or absence of endophyte and/or drought showed no effect on aphid population in the test plants. For the application of this study over broad ecological zones, surveillance of 43 populations was conducted for checking endophyte infection, including commercial stock, germplasm resources, and wild populations. Variation in the frequency of endophytes ranged from 0% to 100%. Where higher frequency was calculated for wild populations as compared to the germplasm resources. Natural variation in the frequencies of endophytes along with the heritable mode of transmission of endophytes from plants to the seeds may provide opportunities for climate change to disturb selection process on maintenance of the endophytic symbiosis in *E. virginicus*.

Hubbard et al. (2012) were of the view that the germination stage of seeds is very crucial for the survival of plants and maintenance of the recommended plant population per unit area under stress conditions. It was hypothesized that the germination capacity of wheat seeds can be improved, under stress conditions like drought and heat, with the help of fungal endophytes. This experiment used the hydrothermal time (HTT) model of germination, which is descriptive model for prediction of the time and energy of germination (EG) under controlled conditions. The HTT and EG were used, for the very first time in this experiment, to study whether researchers can enhance the drought and/or heat resistance in wheat seeds with one and/or more endophytic fungi species. Infecting with fungal endophytes significantly increased the percent germination of wheat. It also improved HTT and EG values, and increased the wheat tolerance to drought and/or heat in terms of fresh weight of treated seedlings. Parameters measured after stress in infected wheat seeds depicted no significant difference with the untreated seeds kept under normal conditions (without stress).

Kane (2011) found that endophytic fungi *Neotyphodium lolii* often infects the perennial ryegrass (*Lolium perenne*). Host growing, survival, and reproductive behavior can be altered significantly due to its infection. Endophyte collected from different areas of the world viz. Morocco, Italy, Turkey, and Tunisia were used to infect the perennial ryegrass and the effect of infection was studied on drought tolerance. Sixty infected (E+) individuals from each set were sown in greenhouse. Fifty percent population of these test plants were treated with a fungicide before sowing to eliminate the endophyte (E−). During this experiment, test plants were not watered for 10–14 days (twice) to give drought stress followed by 1 week of recovery period after each drought period. In the light of these experiments, it was observed that infected plants shown more number of tillers, more tiller lengths, dry mass, and green shoot mass under drought conditions than uninfected plants. It showed that this association has a positive effect on endophyte fungus on the host. Several tillers and tiller length showed significant interaction among treatment, population, and fungal infection for 4 of 6 populations. This study documented the positive effect of endophyte inoculation on a commonly cultivated grass species among wild populations. These findings indicated that the inoculation of endophytic fungi in perennial grasses can help mediate the effect of different stress conditions like drought and/or heat and there can be a selective benefit for grasses from peculiar Mediterranean areas.

Molecular effect of drought tolerant endophytes

Sherameti et al. (2008) worked on an endophytic fungal species viz. *Piriformospora indica* which is isolated from the roots of various plants. This experiment involved growing 2.5 weeks old seedlings of *Arabidopsis*, co-cultivated with endophytic fungus or untreated (in case of control) for 9 days, and their testing against drought stress. Seedlings of *Arabidopsis*, inoculated with the fungus grew successfully, while the untreated control was unable to grow under drought stress. Treatment with endophyte resulted in 3X more fresh weight and 2X more chlorophyll contents than the control. Under drought conditions, photosynthetic activity was lower decrease was observed in the treated while a severing decline in photosynthetic activity was observed in the uncolonized seedlings with distinct symptoms of drought stress like withering. With the increased duration of exposure seedlings to drought viz. 72-84 hours, in uninoculated seedlings only 0-10% reached to reproductive stage. In the case of colonized seedlings around 72 hours of drought resulted in 59% of a seedling reaching reproductive stage while after 84 hours of exposure 47% of the seedlings reached the reproductive stage successfully. A shorter exposure (3h) of treated seedlings to drought stress resulted in a high level of the increased transcript level of various drought-related genes viz. Early Response To Dehydration1, Response To Dehydration 29A, Dehydration-Response Element Binding Protein 2A, ANAC072, phospholipase Dδ, SALT-, And Drought-Induced Ring Finger1, Cbl-Interacting Protein Kinase3, calcineurin b-like protein (cbl)1, and the histone acetyltransferase (HAT). While in untreated seedlings a little increase in transcript level of drought associated genes was observed. These findings indicate that P. indica is responsible for inducing a set of drought-related genes in Arabidopsis thus leading to drought tolerance in Arabidopsis. Additionally, after transferring to soil the transcriptome of CBL1, phospholipase Dδ and HAT in P. indica–treated seedlings, which can aid them in better survival.

Effect of drought tolerant endophytes on phytochemicals

Waqas et al. (2012), isolated and studied the potential of two fungal endophytes in increasing the tolerance against abiotic stressors like drought and salinity by secreting phytohormones (indoleacetic acid (IAA) and gibberellins (GAs). The LWL2 strain of the fungus *Phoma glomerata* and LWL3 of *Penicillium* sp. enhanced the shoot and its relevant growth features of mutant Dongjin-beyo and *Waito-C* rice genotypes which are deficient in GAs. Bioactive forms of GAs (GA_1, GA_3, GA_4, and GA_7) were isolated from the pure cultures of the test fungi endophytes in different quantities. The IAAs were also found in the culture of *Penicillium* sp. and *P. glomerata*. In the next series of experiments, test fungal endophytes were used to infect cucumber plants. The endophytic inoculation was the reason of significant increase in the plant biomass and other growth parameters than the control plants under salinity stress induced by sodium chloride and polyethylene glycol and under water deficit conditions. A high quantity of essential nutrients viz. calcium, potassium, and magnesium were assimilated in the infected plants when compared to the control plants. The host-benefit ratio increased in the inoculated cucumber plants when compared to the uninoculated plants. Also, inoculated plants were less prone to salt stress than uninoculated control. The mutualistic-relationship of endophytes helped the infected plants to withstand the abiotic stress by mediating the bioactivities of decreased phytohormones viz. catalase, glutathione, polyphenol oxidase, and peroxidase. Downregulation of abscisic acid, varied levels of jasmonic acid, and enhanced level of salicylic acid under stress conditions were governed by the endophyte-interaction. Concluding, the two test endophytic fungal species significantly influenced the host plant's physiology during stress conditions.

Effect of drought tolerant endophytes on physiology

According to Swarthout et al. (2009), *Neotyphodium coenophialum* Morgan-Jones and Gams], is found in the aerial parts of tall fescue, which is transferred via seeds of the host-plant. Protection against herbivory and tolerance against drought stress are two important benefits of its infection on the tall fescue grass. Effect of endophyte infection on the decrease in leaf stomatal conductance effect the prompt water-use efficiency (WUE), in (E−) Kentucky-31 under controlled conditions for 10 weeks, was studied. After 6 weeks of germination, test plants were cut and then permitted to grow again under low and high soil moisture conditions. In low soil moisture treatment, after one week of cutting, soil moisture was decreased for 2 weeks until a decrease in stomatal conductance to 100 mmol m^{-2} s^{-1} was observed which is an indicator of drought stress. Under water sufficient conditions, no significant difference regarding WUE was calculated among inoculated and uninoculated plants. While under severe drought conditions infected plants shown higher WUE than uninfected plants. There was a 18-fold decrease in mean WUE and 70-fold decrease in photosynthesis in the uninfected plants under drought conditions. While no difference was observed in WUE and a 4-fold reduction in photosynthesis among normal and drought bearing infected plants after 21 days. Significantly equal transpiration rate was observed in both infected and uninfected plants under severe drought conditions. While a significant difference regarding WUE was mainly due to high photosynthetic rates of infected plants than uninfected plants. However, this research work was unable to explain the variation of photosynthetic rates between infected and uninfected plants under water deficit conditions.

Role of endophytes and nutrient availability to plants

Plants need various micro and macronutrients for optimum growth and development (Welch and House, 1984). Most of the soils in Pakistan are sandy-sandy loam, which have major issue of leaching of nutrients away from the plants. For this purpose, endophytes can play a vital role in holding them and their *in planta* availability.

Effect of endophytes on bio-availability of nitrogen

In rice cultivation, nitrogen is the most common limiting nutrient, as 1 kg of nitrogen is required to generate 15–20 kg of grain (Ladha & Reddy 2003). The rice crop's long-term nitrogen nutrient availability will be greatly enhanced if biological nitrogen fixation is fully exploited. Fertilizer N is frequently disseminated into floodwater, where it is readily absorbed if applied at the right moment to satisfy the plant's demand. Gaseous emission, on the other hand, loses the N that isn't quickly absorbed. As a result, N fertiliser is inefficiently applied, and average rice recovery is low (IRRI, 2020). Bacterial endophytes inhabit cereal roots, stems, and leaves, and so face far less competition from other microorganisms for carbon substrates than rhizosphere bacteria, and may even excrete some of their fixed nitrogen straight into the plant (Stoltzfus et al. 1998). Furthermore, endophytic bacteria can transform N2 from the atmosphere into mixed N that plants can use while posing no threat to them (Hongrittipun et al. 2014). Some endophytic bacteria can fix nitrogen from the air and convert it to plant-useable nitrogen molecules. From the stems, roots, and leaves of five different rice (Oryza sativa L.) cultivars, 123 endophytic bacteria have been identified. The bacteria's nitrogenase activity was further validated by an acetylene reduction assay. Burkholderia cepacia (CS5), Citrobacter sp. (CR9), Citrobacter sp. (SS5), Citrobacter sp. (SS6), Bacillus amyloliquefaciens (25R14), Bacillus amyloliquefaciens (SR1), and Bacillus thuringiensis (SR1) had the highest nitrogenase activity (25R2). Rice inoculation can dramatically increase nitrogen concentration in the root zone of the plant (Hongrittipun et al. 2014)

Effect of endophytes on bioavailability of Phosphorus and Potassium

Several rhizobial strains, including Rhizobium phaseoli (A2, A3, S17, N8), Rhizobium leguminosarum (LSI-23, LSI-26, LSI-29, LSI-30), and Mesorhizobium ciceri (CRI-28, CRI-31, CRI-32, CRI-38), considerably increased numerous indices, including number of tillers (46%) and plant biomass (18%). Furthermore, paddy's phosphate and potassium levels increased (Hussain et al. 2009). Indole acetic acid (IAA)-overproducing Burkholderia cepacia mutants greatly increased phosphorus and potassium uptake (RRE25). Following nitrous acid mutagenesis, nine mutants with altered IAA biosynthesis were identified. Rice plants inoculated with bacterial endophytes grow faster because they produce more IAA, which increases nutritional availability and leads to root system proliferation (Singh et al. 2013).

Effect of endophytes on plant physical growth paramaters

Numbers of tillers, chlorophyll content, plant height, photosynthetic rate, antioxidant enzyme activity, and grain yield are all essential physical plant growth characteristics to consider when assessing plant growth and development. Plant growth promoting rhizobacteria (PGPR) are bacteria that promote plant growth without causing disease stress. In contrast, only plant growth promoting (PGP) agents that are properly adapted for the target crop's ecological conditions should be tested (Etesami et al. 2015).

From the bark of Bischofia polycarpa, an endophytic Phomopsis sp. was isolated. Its artificial inoculation of rice plants with the endophyte demonstrated that the endophyte and the infected rice plant had formed a mutualistic relationship. The number of tillers, chlorophyll content, plant height, photosynthetic rate, antioxidant enzyme activity, and grain yield were all found to be positively influenced. Endophytic Phomopsis sp. could be beneficial as a growth-promoting microbial agent for improving rice plant vigour and quality (Yuan et al. 2007).

Despite good fertilisation of the field, rice crops require a large amount of nitrogen fertiliser, but its availability in planta is limited due to a variety of causes. Endophytes that fix nitrogen in rice plants may lessen the need for nitrogen fertilisers by making nutrient availability simpler. In the greenhouse, rice seedlings infected with nitrogen-fixing endophytes derived from the early successional plant species willow (Salix sitchensis C. A. Sanson ex Bong.) and poplar (Populus trichocarpa Torr. & A. Gray) showed substantial growth under N-limited conditions. Infected rice plants had more tillers, biomass, and plant height than non-infected rice plants. Endophytes infiltrated diseased rice plants' leaves, roots, and foliage. Finally, nitrogen-fixing endophytes from willow and poplar can colonise rice plants, resulting in increased plant development under nitrogen-deficient situations (Kandel et al. 2015).From the roots of a Thai jasmine rice plant, an endophytic Streptomyces sp. GMKU 3100 was identified (Oryza sativa L. cv. KDML105). Experiments with Streptomyces sp. GMKU 3100 inoculates under controlled settings revealed that plant growth, root and shoot length, as well as biomass, were greatly improved when compared to untreated controls and siderophore-deficient mutant treatments. To summarise, endophytic actinomycetes have the potential to be used as biofertilizers in agriculture that are both safe and environmentally benign (Rungin et al. 2012).

Effect of endophytes on plant hormones

Effect on Indole acetic acid (IAA)

Indole-3-acetic acid (IAA) is a phytohormone that can affect plant development in both positive and negative ways. Many bacteria, both plant growth promoters and phytopathogens, have the potential to manufacture IAA (Duca et al. 2014). A total of 1035 yeast isolates were obtained from sugarcane and rice leaves, with the majority of them being selected for their ability to produce indole-3-acetic acid (IAA). Thirteen isolates from four yeast species, Cryptococcus flavus (DMKU-RE12, DMKU-RE19, DMKU-RE67, and DMKU-RP128), Hannaella sinensis (DMKU-RP45), Torulaspora globosa (DMKU-RP31), and Rhodosporidium paludigenum (DMKU-RP301), were capable of producing significant IAA levels. . T. globosa DMKU-RP31 is one of them, and it could be used in two ways: to boost plant growth and as a biocontrol agent. In addition, four C. flavus strains were identified as potential candidates for IAA production (Nutaratat et al. 2014).

Conclusion

It was concluded that Rice (Oryza sativa L.) is the most widely grown crop in terms of both production and area under cultivation. Each year, abiotic conditions cause a 50% loss in the rice crop. Drought, salinity, nutrition, and heat stress are major abiotic stresses that are controlled by multiple genes and cannot be addressed by improving agronomic methods or inserting one or two genes into plants. Endophytes, which live predominantly in the tissues of the host plant, can be important in sustainable agriculture because of the multiple benefits they provide. Though endophytes have been shown to have harmful activity in recent studies, the mutualistic, non-pathogenic, and/or helpful characteristics of endophytes are more prevalent. As a result, only the positive characteristics of endophytes will be explored. Although fungi are the most commonly identified endophytes from plant tissues, endophytes are not confined to fungi; in fact, numerous bacterial species have been reported as endophytes, and in some situations, they prove to be more useful than fungal endophytes. There hasn't been any current research on the use of bacterial and fungal endophytes to improve plant tolerance to abiotic stresses. As a result, this review has provided a recent update on the role of endophytes in rice plant improvement (s). This review will aid researchers and scientists in identifying the most promising endophytes in the field and using them to farmers' benefit.

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