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Seed Biopriming by Endophytes for Enhanced Field Performance of Hybrid Maize (*Zea mays* L.) COH(M) 8

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ABSTRACT

Background: Endophytes are generally defined as symptomless fungal or bacterial microorganisms, which are associated with their host plants by colonizing the internal plant parts, which has made them as a valuble tool in improving crop performance in agriculture. With this view, the study was conducted to assess the efficacy of endophytes when used as seed biopriming agent on plant growth and seed yield of hybrid maize COH(M) 8 under field conditions during 2021-2022.

Methods: The present study was carried out with different endophytic seed priming for 12 hrs duration at the ratio of 1:1 volume/ volume with *Beauveria bassiana* @ 5%, *Metarhizium anisopliae* @ 5% and *Bacillus subtilis* @ 8% along with hydro priming and untreated control combined with foliar spray at 30th and 50th days after sowing (DAS).

Result: The results revealed that among various endophytes used in this study, *M. anisopliae* @ 5% when used for biopriming of seeds as well as for foliar spraying @ 0.5% maximized the plant height (208.4 cm @ 45 DAS and 247.8 cm @ 75 DAS), leaf length (76.0 cm) chlorophyll (chl) content (*chl a* 0.423 mg/g, *chl b* 0.229 mg/g and *total chl* 0.652 mg/g), cob length (21.2 cm), seed yield/plot (6.89 kg) and seed yield/ha (5744 kg).

Key words: Endophytes, Maize, *Metarhizium anisopliae,* Seed priming, Seed yield.

INTRODUCTION

Maize (*Zea mays* L.) belongs to the poaceae family and is the third most important cereal crop after wheat and rice and is grown throughout the year in India. Maize is a C_4 plant, makes effective use of moisture and sunlight to produce high yields and total dry matter (Bell, 2017). It is a cross-pollinated crop native to Mexico and has wider adaptability under varied agro-climatic conditions with the highest genetic gain among the cereals. The demand of maize production on a global scale is rising as a source of food, oil, forage and biofuel for the growing world's population.

Endophytic microorganisms are generally known as microbes that colonize the plant parts and that do not harm the plant. They improve plant growth by secreting phytohormones and consequently help in nutrition improvement using bidirectional nutrient transfer and enhancement of the health of plants by protecting them against phytopathogens (Shen *et al.,* 2019). Endophytes are numerous and have been found in many plants; they became important due to their ability to create a wide range of bioactive compounds and essential enzymes (Rajamanikyam *et al.,* 2017). When endophytes are inoculated into a plant, they usually result in significant increase of biomass, as well as aid commercial agriculture (Shen *et al.,* 2019).

Endophytes are found in all or most of the plants and in most cases, endophytes are transmitted through seeds, where they begin to promote plant development and health as soon as the seeds germinate (Kandel *et al.,* 2017). Some other endophytes can be found in the soil and provide benefits to plants (Verma and White, 2018). One of the most important aspects of quality seeds is the production of pest and disease-free seeds which will enhance the vigour, viability and optimum field stand. This can be achieved through seed biopriming with endophytes. During seed priming with endophytes, it enters into the seeds and adapts to the existing conditions. It is capable of fixing nitrogen, solubilization of phosphate, enhancing the uptake of phosphorus and production of siderophores and plant hormones such as auxin, abscisic acid, ethylene, GA_3 and

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IAA, which are important for plant growth and development (Xu *et al.,* 2014). Besides it offers protection of the host plant against various stress condition. with this view, the present study has been undertaken to get enhanced field performance of Hybrid maize COH(M) 8 through seed biopriming with endophytes.

MATERIALS AND METHODS

Collection of experiment materials

The genetically pure and freshly harvested seeds of maize hybrid COH(M) 8 collected from the Department of Millet, Tamil Nadu Agricultural University, Coimbatore used as source material for this study. The endophytic microorganisms *Viz., B. bassiana, M. anisopliae* and *B. subtilis* were used for this study. The population dynamics or CFU/ml solution of *B. bassiana* and *M. anisopliae* through Potato Dextrose Agar (PDA) medium *and B. subtilis* through Luria-Bertani (LB) medium was 2×10^{-8}.

Field experiment

The field experiment was carried out in field No 37D, Department of Seed Science and Technology, TNAU, Coimbatore in 2021-2022 and the maximum and minimum temperature of 34.5°C and 20.5°C respectively and an average rainfall of 589 mm were recorded. The experiment was conducted, with the seeds bioprimed with endophytes along with foliar application of fungal and bacterial endophytes to study the morphological, reproductive and seed yield attributes. Endophytic priming solution was prepared using double distilled water and seeds were soaked in priming solution for 12 hrs at the ratio of 1:1 volume/volume and the temperature of 10-15°C was maintained. The seed was removed from the solution after the priming (12 hrs) and rinsed with water and then dried back to their original moisture content. The treatment includes T_0 - Control, T_1 - Hydro priming, T_2 - Seed priming with *B. bassiana* 5%, T_3 - Seed priming with *M. anisopliae* 5%, T_4 - Seed priming with *B. subtilis* 8%, T_5 - Seed priming with *B. bassiana* 5% and foliar spray of *B. bassiana* 0.5%, T_6 - Seed priming with *M. anisopliae* 5% and foliar spray of *M. anisopliae* 0.5% and T_7 - Seed priming with *B. subtilis* 8% and foliar spray of *B. subtilis* 0.5% with three replication in a randomized block design (RBD). The foliar spray was given at 30th and 50th DAS. the size of plot was 4.0×3.0 m^2 with the crop spacing of 60 cm $\times$ 30 cm. The observations were taken at different crop growth stages.

Observations recorded

Field emergence (%)

Field emergence was recorded by counting the number of hills germinated in each plot at fifteen days after sowing.

Plant height (cm)

Plant height was measured in ten randomly selected plants from each treatment in each replication, from the base to the tip of the leaf and the mean value was expressed in cm.

No. of leaves/ plant

The number of leaves on ten randomly chosen plants in each plot was counted and the mean number was computed.

Leaf length (cm)

The leaf length was observed at the 3rd leaf from the top of the plant using a scale in randomly selected ten plants and the mean length was depicted in centimetre.

Leaf breadth (cm)

The leaf breadth was taken at the 3rd leaf from the top of the plant using a scale in randomly selected ten plants. Mean values was expressed in centimetre.

Chlorophyll content (mg/g)

Leaf chlorophyll was measured by the method suggested by Yoshida *et al.* (1971) and the optical density of extract was measured at 645 nm, 663 nm and 652 nm in a spectrophotometer.

Days to 1st and 50% tasselling (DAS)

The number of days taken for the appearance of first tasselling and the number of days taken by 50% of the plants in each plot for tasselling were recorded.

Days to 1st and 50% silking (DAS)

The number of days taken for the appearance of first silking and then days taken by 50% of the plants in each plot for silking were observed.

Cob length and breadth (cm)

In randomly selected ten plants, the length and breadth of the cob were measured using a measuring scale and the mean value was calculated and expressed in centimeters.

100 seed weight (g)

Hundreds of seeds were counted with eight treatment in each replications and weight was observed and expressed in grams.

Seed yield per plot (kg)

Seeds were threshed from each plot separately, dried to 13% moisture content, weighed and expressed in kilogram. Seed yield/ha (kg/ha) Computed seed yield was calculated from plot yield and expressed in kg per hectare.

Statistical analysis

The analysis of variance was carried out and a comparison was done by Duncan's Multiple Range Test (DMRT). The mean difference is significant at the P-values < 0.05. Statistical analysis was performed using the SPSS 16.0 software (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

Sustainable agriculture is fundamentally concerned with improving and decreasing the adverse effects of agricultural production. Global agriculture must expand food production to meet the needs of a growing population and decrease its dependency on synthetic chemicals. So, utilizing the numerous advantageous interactions that take place between plants and microbes is crucial. It enhances the nitrogen fixation, acquisition and uptake of essential nutrients, the encouragement of shoot and root growth and the control or suppression of disease to boost plant growth and development.

In this regard, the results revealed that seed biopriming with endophytes exhibited significant effects on field emergence. Priming with *M. anisopliae* @ 5% (T_3) recorded the maximum increase of field emergence (90%) that was 5.88% more over nonprimed seeds (T_0) (85%) (Fig 1). An increase in germination percentage might be due to the combined effect on the production of hydrolytic enzymes and growth hormones like IAA and gibberellins through endophytic seed treatments (Schulz and Boyle, 2005). This is in agreement with other studies showing that priming mainly improves germination as a result of the enhanced water uptake and more favourable water relations and also increases the production of hydrolytic enzymes in primed seeds (Lechowska *et al.,* 2019). Earlier reports corroborate the findings of this study by Yuan *et al*. (2007) who observed that the germination of rice seeds treated with endophytes were significantly higher than without seed priming.

The maximum plant height at 15 DAS (58.5 cm) was observed in seed priming with *M. anisopliae* @ 5% (T_3) whereas control (T_0) registered the minimum plant height (53.8 cm). Seed priming compined with foliar spray of *M. anisopliae* (T_6) recorded higher plant height at 45 DAS (208.4 cm) and 75 DAS (247.8 cm), with an increase of 9.62% and 10.28% respectively over control (Table 1). According to Elena *et al.* (2011), inoculating *M. anisopliae* with tomato plants increased plant biomass, particularly plant height, root length and dry biomass from the roots and shoots. Additionally, 10, 15 and 30 days after *M. robertsii* inoculation, tomato plantlets exhibit an increase in plant height, root length and shoot dry biomass compared to control plants (Siqueira *et al.,* 2020). The finding was in line with *M. anisopliae* colonization having enhanced growth in soybean (Khan *et al.,* 2012) and maize (Gayathri *et al.,* 2020). The results are supported by Endophytes that have been producing phytohormones like particularly gibberellins (GAs) and indole-3-acetic acid (IAA), which play a role in cell division and elongation thereby increasing plant growth.

In terms of leaf parameters, endophyte treatments do not influence the number of leaves and leaf breadth. In the case of leaf length, seed priming and foliar spraying with endophytes recoded higher leaf length *viz., B. bassiana* (T_5) (76.1 cm), *M. anisopliae* (T_6) (76.0) and *B. subtilis* (T_7) (75.5 cm) and control (T_0) registered the lowest one (Table 2). A similar result was observed in treated broad bean seeds with *M. anisopliae* and *B. bassiana* (Jaber and Enkerli, 2017).

The significant difference was observed in chlorophyll (*chl*) a and b and total chlorophyll content in endophytic treatments. The result revealed that seed priming and foliar spraying of *M. anisopliae* (T_6) recorded maximum value of *chl* a 0.423 mg/g, *chl* b 0.229 mg/g and total *chl* 0.652 mg/g. Control (T_0) recorded the lowest valve of *chl* a 0.367 mg/g, *chl* b 0.195 mg/g and total *chl* 0.562 mg/g (Fig 2). *M. anisopliae* has enhanced chloroplast metabolism due to increased chlorophyll content (Shi *et al.,* 2010). This outcome is consistent with that of Khan *et al.* (2014), who showed that endophytes inoculated with tomato plants increased the amount of chlorophyll content and additionally, the synthesis of IAA has been shown to increase the production of photosynthetic pigments and metabolites (Duca *et al.,* 2014). The previous research finding was in line with endophytic bacteria had enhanced the chlorophyll content registered in mustard, which could significantly increase the enzymes needed for chlorophyll biosynthesis (Kang *et al.,* 2014).

In phenological characters, days taken to initiation of flowering were reduced in seed priming with foliar spray when compared to other treatments, but there was no significant difference observed in days to 1st tasselling, 50 percent tasselling and days to 50 percent silking. A significant difference was observed only in days to 1st silking in both priming and foliar spraying of *B. bassiana* (T_5), *M. anisopliae* (T_6) and *B. subtilis* (T_7) at two stages (Table 3). The duration was higher in control plants, plant growth and development are enhanced by endophytes through secreting phytohormones and improved nutrition uptake through bidirectional nutrient exchange given by Andreozzi *et al.* (2019).

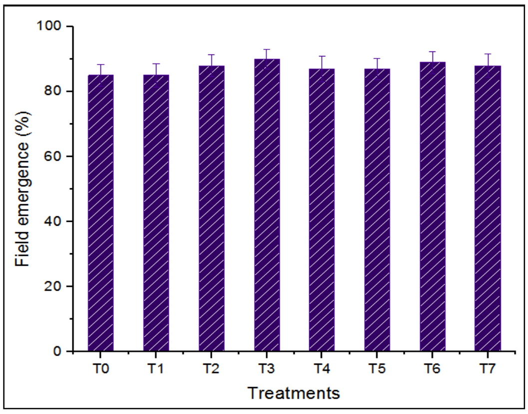

Fig 1: Effect of endophytic treatments on field emergence (%) in maize COH(M) 8.

Table 1: Influence of endophytic treatments on plant height of maize COH(M) 8.

Treatments	Plant height (cm)		
	15 DAS	45 DAS	75 DAS
T_0	53.8±0.35^{e}	190.1±0.67^{f}	224.7±1.12^{e}
T_1	55.3±0.23^{d}	191.9±0.67^{e}	225.4±1.07^{de}
T_2	58.4±0.36^{ab}	194.1±0.47^{d}	228.1±1.20^{de}
T_3	58.5±0.31^{a}	195.0±0.54^{d}	228.8±1.16^{d}
T_4	57.5±0.35^{bc}	193.6±0.47^{d}	228.3±0.94^{d}
T_5	58.1±0.33^{abc}	201.7±0.65^{b}	240.3±1.16^{b}
T_6	58.4±0.33^{ab}	208.4±0.52^{a}	247.8±1.35^{a}
T_7	57.4±0.28^{c}	199.9±0.48^{c}	236.1±1.25^{c}

Seed yield parameters such as cob length and seed yields were significantly influenced by the endophytes, but cob breadth and 100 seed weight were not influenced by the endophytic treatments. The maximum cob length (21.2 cm) was noticed in priming and foliar spraying of *M. anisopliae* (T_6). While analyzing the seed yield of various treatments, Seed priming and foliar spray of *M. anisopliae* (T_6) recorded a maximum seed yield of 6.893 kg/plot and the control (T_0) recorded the lowest seed yield 6.400 kg/plot. Similarly seed priming and foliar spray of *M. anisopliae* (T_6) increased seed yield (kg/ha) 7.71% over control (Table 4) (Fig 3). Endophytes may improve plant growth through their favourable effects on photosynthesis and chlorophyll content. Because of high photosynthetic activity and increase in nutrient exchange thereby accumulation of more dry weight (*e.g.*, increased primary metabolites *viz.,* sugars, proteins and fatty acids), which could have lead to an increased seed yield. The result was in concurrence with Stefan *et al.* (2013) who observed the higher yield of bean plants inoculated with endophytes associated with higher photosynthetic activities. The present results showed that the seed yield increased significantly in inoculated plants, as that of previous research finding which was in line with the Inoculation of *M. anisopliae* in maize seeds resulting in a significant increase in seed yield (Kabaluk and Ericsson, 2007). Similarly, inoculation with

Table 2: Influence of endophytic treatments on leaf characters of maize COH(M) 8.

Treatments	No. of leaves/ plant	Leaf length (cm)	Leaf breadth (cm)
T_0	17±0.05^{ns}	72.1±0.52^{b}	7.9±0.09^{ns}
T_1	17±0.03^{ns}	72.2±0.37 ^{b}	7.8±0.09^{ns}
T_2	17±0.06^{ns}	73.4±0.18^{b}	7.9±0.07^{ns}
T_3	17±0.03^{ns}	73.0±0.55^{b}	7.9±0.14^{ns}
T_4	17±0.04^{ns}	72.6±0.27^{b}	8.0±0.09^{ns}
T_5	17±0.03^{ns}	76.1±0.61^{a}	8.0±0.14^{ns}
T_6	17±0.20^{ns}	76.0±0.58^{a}	8.0±0.11^{ns}
T_7	17±0.18^{ns}	75.5±0.54^{a}	7.9±0.14^{ns}

Table 3: Influence of endophytic treatments on phenological characters of maize COH(M) 8.

Treatments	Days to 1st tasselling (DAS)	Days to 50 per cent tasselling (DAS)	Days to 1st silking (DAS)	Days to 50 per cent silking (DAS)
T_0	50±0.46^{ns}	52±0.27^{ns}	51±0.16^{b}	53±0.26^{ns}
T_1	50±0.40^{ns}	52±0.23^{ns}	51±0.21^{b}	53±0.38^{ns}
T_2	50±0.57^{ns}	52±0.12^{ns}	51±0.25^{b}	53±0.25^{ns}
T_3	50±0.43^{ns}	52±0.19^{ns}	51±0.26^{b}	53±0.35^{ns}
T_4	50±0.56^{ns}	52±0.23^{ns}	51±0.19^{b}	53±0.23^{ns}
T_5	49±0.40^{ns}	51±0.17^{ns}	50±0.14^{a}	52±0.27^{ns}
T_6	49±0.41^{ns}	51±0.17^{ns}	50±0.19^{a}	52±0.31^{ns}
T_7	50±0.51^{ns}	51±0.29^{ns}	50±0.18^{a}	52±0.43^{ns}

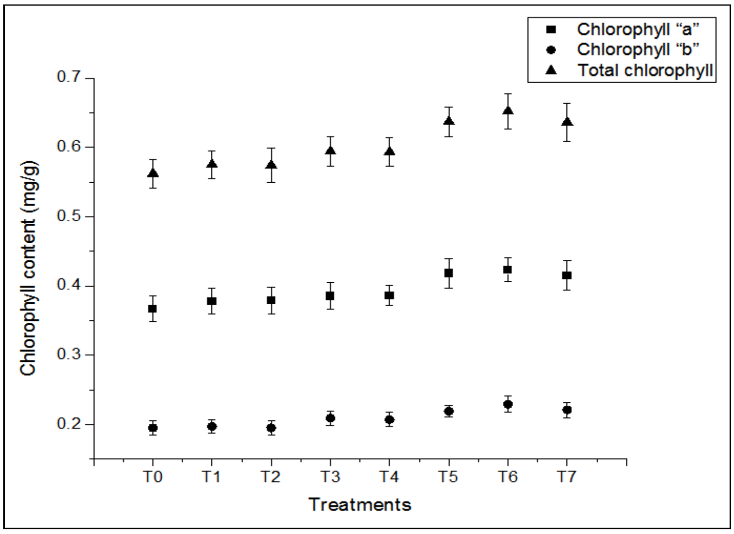

Fig 2: Effect of endophytic treatments on chlorophyll content in maize COH(M) 8.

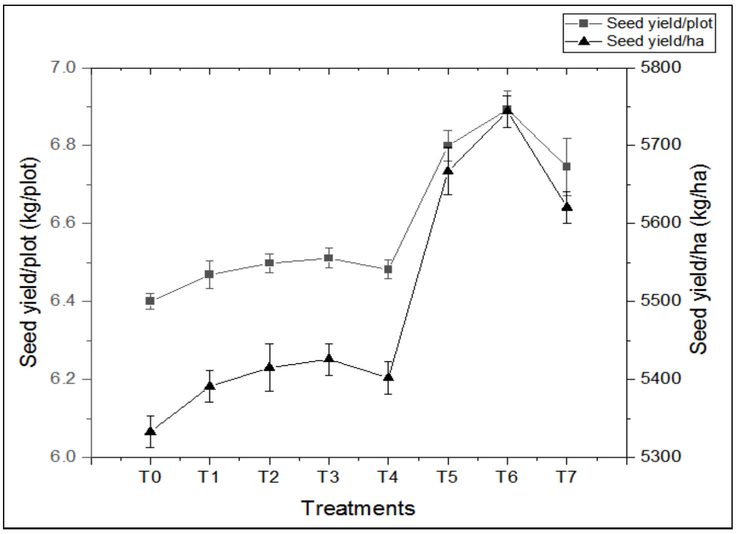

Fig 3: Effect of endophytic treatments on seed yield of maize COH(M) 8.

Table 4: Influence of endophytic treatments on yield attributes of maize COH(M) 8.

Treatments	Cob length (cm)	Cob breadth (cm)	Seed yield/plot (kg/plot)	100 seed weight (g)
T_0	19.9 ± 0.10^{c}	16.1 ± 0.12^{ns}	6.400 ± 0.03^{b}	36.13 ± 0.25^{ns}
T_1	19.6 ± 0.17^{c}	16.2 ± 0.23^{ns}	6.469 ± 0.01^{b}	36.26 ± 0.31^{ns}
T_2	20.1 ± 0.20^{c}	16.4 ± 0.19^{ns}	6.498 ± 0.03^{b}	36.28 ± 0.26^{ns}
T_3	20.9 ± 0.28^{ab}	16.5 ± 0.27^{ns}	6.511 ± 0.04^{b}	36.29 ± 0.19^{ns}
T_4	20.7 ± 0.09^{b}	16.3 ± 0.18^{ns}	6.482 ± 0.07^{b}	36.23 ± 0.21^{ns}
T_5	19.9 ± 0.04^{c}	16.6 ± 0.23^{ns}	6.800 ± 0.03^{a}	36.57 ± 0.22^{ns}
T_6	21.2 ± 0.09^{a}	16.5 ± 0.14^{ns}	6.893 ± 0.11^{a}	36.68 ± 0.22^{ns}
T_7	20.9 ± 0.28^{ab}	16.7 ± 0.26^{ns}	6.745 ± 0.05^{a}	36.55 ± 0.17^{ns}

B. bassiana enhances the plant growth and increases the seeds yield of soybean recorded by Russo *et al.* (2019)
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CONCLUSION

Based on the results, it can be concluded that the selected endophytes *viz., Beauveria bassiana, Metarhizium anisopliae* and *Bacillus subtilis* inoculated in the form of both priming and foliar application had enhanced the maize plant growth and development. It is concluded that among the endophytes *M anisopliae* seed priming and foliar application had improve the plant growth, photosynthetic pigments and seed yield of maize under field conditions.

Conflict of interest: None.

REFERENCES

Andreozzi, A., Prieto, P., Mercado Blanco, J., Monaco, S., Zampieri, E., Romano, S., Vale, G., Defez, R. and Bianco, C. (2019). Efficient colonization of the endophytes *Herbaspirillum huttiense* RCA24 and Enterobacter cloacae RCA25 influences the physiological parameters of *Oryza sativa* L. cv. Baldo rice. Environmental Microbiology. 21: 3489-3504. https://doi.org/10.1111/1462-2920.14688.

Bell, J. (2017). Corn Growth Stages and Development. Texas A and M Agri Life Research and Extension Center, Amarillo.

Duca, D., Lorv, J., Patten, C.L., Rose, D. and Glick, B.R. (2014). Indole-3-acetic acid in plant-microbe interactions. Antonie Van Leeuwenhoek. 106: 85-125.

Elena, G. J., Beatriz, P. J., Alejandro, P. and Lecuona, R. E. (2011). *Metarhizium anisopliae* (Metschnikoff) Sorokin promotes growth and has endophytic activity in tomato plants. Advance Biological Research. 5(1): 22-27.

Gayathri, M., Jerlin, R., Kennedy, J.S. and Sasthri, G. (2020). Seed endophytic treatment for enhancing seed quality in maize (*Zea mays* L.). Multilogical in Science. 10: 1108-1112.

Jaber, L.R. and Enkerli, J. (2017). Fungal entomopathogens as endophytes: Can they promote plant growth?. Biocontrol Science and Technology. 27: 28-41. https://doi.org/10.1080/09583157.2016.1243227.

Kabaluk, J.T. and Ericsson, J.D. (2007). *Metarhizium anisopliae* seed treatment increases yield of field corn when applied for wireworm control. Agronomy Journal. 99(5): 1377-1381. https://doi.org/10.2134/agronj2007.0017N.

Kandel, S.L., Joubert, P.M. and Doty, S.L. (2017). Bacterial endophyte colonization and distribution within plants. Microorganisms. 5(4): 77. https://doi.org/10.3390/microorganisms5040077.

Kang, S.M., Radhakrishnan, R., You, Y.H., Joo, G.J., Lee, I.J., Lee, K.E. and Kim, J.H. (2014). Phosphate solubilizing *Bacillus megaterium* mj1212 regulates endogenous plant carbohydrates and amino acids contents to promote mustard plant growth. Indian Journal of Microbiology. 54(4): 427-433. https://doi.org/10.1007/s12088-014-0476-6.

Khan, A.L., Hamayun, M., Khan, S.A., Kang, S.M., Shinwari, Z.K., Kamran, M., Rehman, S., Kim J. G. And Lee, I. J. (2012). Pure culture of *Metarhizium anisopliae* LHL07 reprograms soybean to higher growth and mitigates salt stress. World Journal of Microbiology and Biotechnology. 28: 1483-1494. doi: 10.1007/s11274-011-0950-9. Epub 2011 Nov 22. PMID: 22805930.

Khan, A.L., Waqas, M., Kang, S.M., Al-Harrasi, A., Hussain, J., Al-Rawahi, A., Al-Khiziri., S., Ullah, I., Ali, L., Jung, H. and Lee, I.J. (2014). Bacterial endophyte *Sphingomonas* sp. LK11 produces gibberellins and IAA and promotes tomato plant growth. Journal of Microbiology. 52(8): 689-695. https://dio.org/10.1007/s12275-014-4002-7.

Lechowska, K., Kubala, S., Wojtyla, £., Nowaczyk, G., Quinet, M., Lutts, S. and Garnczarska, M. (2019). New insight on water status in germinating *Brassica napus* seeds in relation to priming-improved germination. International Journal of Molecular Sciences. 20: 540. https://doi.org/10.3390/ijms20030540.

Rajamanikyam, M., Vadlapudi, V. and Upadhyayula, S.M. (2017). Endophytic fungi as novel resources of natural therapeutics. Brazilian Archives of Biology and Technology. 60. https://doi.org/10.1590/1678-4324-2017160542.

Russo, M.L., Pelizza, S.A., Vianna, M.F., Allegrucci, N., Cabello, M.N., Toledo, A.V., Mourelos, C. and Scorsetti, A.C. (2019). Effect of endophytic entomopathogenic fungi on soybean *Glycine max* (L.) Merr. growth and yield. Journal of King Saud University-Science. 31(4): 728-736. https://doi.org/10.1016/j.jksus.2018.04.008.

Schulz, B. and Boyle, C. (2005). The endophytic continuum. Mycological Research. 109(6): 661-686. https://doi.org/10.1017/S095375620500273X.

Shen, F.T., Yen, J.H., Liao, C.S., Chen, W.C. and Chao, Y.T. (2019). Screening of rice endophytic biofertilizers with fungicide tolerance and plant growth-promoting characteristics. Sustainability. 11(4): 1133. https://doi.org/10.3390/su11041133.

Shi, Y., Lou, K. and Li, C. (2010). Growth and photosynthetic efficiency promotion of sugar beet (*Beta vulgaris* L.) by endophytic bacteria. Photosynthesis Research. 105(1): 5-13. https://doi.org/10.1007/s11120-010-9547-7.

Siqueira, A.C.O., Mascarin, G.M., Gonçalves, C.R., Marcon, J., Quecine, M.C., Figueira, A. and Delalibera Jr, Í. (2020). Multi-trait biochemical features of *Metarhizium* species and their activities that stimulate the growth of tomato plants. Frontiers in Sustainable Food Systems. 4: 137. https://doi.org/10.3389/fsufs.2020.00137.

Stefan, M., Munteanu, N., Stoleru, V. and Mihasan, M. (2013). Effects of inoculation with plant growth promoting rhizobacteria on photosynthesis, antioxidant status and yield of runner bean. Romanian Biotechnological Letters. 18(2): 8132-8143.

Verma, Sp.K. and White, J.F. (2018). Indigenous endophytic seed bacteria promote seedling development and defend against fungal disease in browntop millet (*Urochloa ramosa* L.). Journal of Applied Microbiology. 124(3): 764-778. https://doi.org/10.1111/jam.13673.

Xu, M., Sheng, J., Chen, L., Men, Y., Gan, L., Guo, S. and Shen, L. (2014). Bacterial community compositions of tomato (*Lycopersicum esculentum* Mill.) seeds and plant growth promoting activity of ACC deaminase producing *Bacillus subtilis* (HYT-12-1) on tomato seedlings. World Journal of Microbiology and Biotechnology. 30(3): 835-845. https://doi.org/10.1007/s11274-013-1486.

Yoshida, S., Forno, D.A. and Cock, J.H. (1971). Laboratory Manual for Physiological Studies of Rice. International Rice Research Institute, Los Banos, Phillipines. 70.

Yuan, Z.L., Dai, C.C., Li, X., Tian, L.S. and Wang, X.X. (2007). Extensive host range of an endophytic fungus affects the growth and physiological functions in rice (*Oryza sativa* L.). Symbiosis. 43: 21-28.