ROLE OF ENDOPHYTE CHAETOMIUM GLOBOSUM LK4 IN GROWTH OF CAPSICUM ANNUUM BY PRODUCION OF GIBBERELLINS AND INDOLE ACETIC ACID

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Abstract

Endophytic fungi represent a trove of unexplored natural source of plant hormones like gibberellins (GAs) and indole-acetic acid (IAA). In present study, we isolated eight endophytes from the roots of drought stressed pepper (Capsicum annuum L.) plants. To assess phytohormones secreting potential, culture filtrates (CF) of endophytes were screened on GAs biosynthesis mutant Watio-C rice. Endophyte CAC-1G significantly promoted the shoot growth, chlorophyll content and biomass of Watio-C rice seedlings as compared with CF of Fusarium fujikuroi and distilled water. CAC-1G was identified as strain of Chaetomium globosum LK4 by sequencing internal transcribed spacer regions and phylogenetic analysis of similar sequences. The CF analysis of C. globosum showed the presence of GAs (GA 1 0.67±0.13 ng/ml; GA 4 21.8±1.2 ng/ml; GA 5 0.51±0.11 ng/ml; GA 13 4±0.41 ng/ml; GA 9 1.1±0.2 ng/ml) and IAA (16.71±1.42 µg/ml). The CF of C. globosum had higher GA 4, GA 12 and GA 20 than the CF of F. fujikuroi. The CF containing propagules of C. globosum was applied to the host-pepper plants. The results revealed significantly higher shoot growth, chlorophyll content, plant biomass and leaf area as compared to fungal-free medium and water applied plants. The present results of C. globosum can be reciprocated for improved plant growth and yield at field levels.

Introduction

Endophytic fungi live asymptptomatically within plant tissues have been found in almost all plant species (Saikkonen et al., 1998; Schulz & Boyle, 2005). These poorly known fungi represent a trove of unexplored biodiversity, and a frequently overlooked component of forest (Reinhardt, 2007; Arnold, 2008) and crop ecology (Khan et al., 2011a). The endophyte-host interaction is mutualistic or neutral and may differ among hosts and on the basis of environmental conditions (Saikkonen et al., 1998; Faeth & Fagan, 2002). Endophytic fungi draw three basic benefits from the host plants: nourishment, physical protection and adversities reproduction e.g. members of Clavicipitaceous and Dikarya (Hyde & Soytong, 2008). In return, the host plant is benefited by the endophyte through production of metabolites (e.g. alkaloids, antibiotics, or toxins, growth regulators (Schulz & Boyle 2005, Khan et al., 2011a)), nutrient composition inside tissues, plant hormonal balance, chemical composition of root exudates, physical modification of soil, disease resistance and protection against external calamities (Waller et al., 2005; Rahman & Saiga, 2005; Oses et al., 2008).

These endophytes have been found as a novel source of various kinds of bioactive secondary metabolites (Schulz et al., 2002). However, there are few reports available about the endophytes secreting phytohormones like gibberellins (GAs), auxin etc. Previously, some endophytic fungal strains were reported to produce a variety of physiologically active and inactive GAs. This includes; Fusarium fujikuroi, Spheceloma manihoticola (Bomke et al., 2008) Phaeosphaeria sp. L487 (Kawaiade, 2006), Phaeosphaeria sp., Neurospora crassa (Rademacher 1994), Sesamum indicum (Choi et al., 2005), Cladosporium sp. MI-6 (Hamayun et al., 2010), Aspergillus fumigatus (Khan et al., 2011a) Penicillium junicosum (Khan et al., 2011b), Exophiala sp. LHL08 (Khan et al., 2011c), and Curvularia prouberata etc. These phytohormones producing endophytes have been also reported to play essential role in crop plant growth and metabolism. However, there is little information available on endophytes isolated from extreme environmental conditions.

Chilli pepper (Capsicum annuum L.) is an important vegetable as well as spice crop, used worldwide for domestic and commercial purposes. They are rich source of antioxidants, vitamin C, pro-vitamin A, E, and B (Bosland & Votava, 1999). Pepper is regarded as a sensitive to salinity and drought (Kamber et al., 1992). With expanding human population, food demands have been at sturdy rate and therefore, maintaining plant growth is crucial for crop yield. Symbiosis of such endophytic fungi offers advantages to host plants in transport and assimilation biochemicals necessary for plant growth and counteract biotic and abiotic stresses (Schulz & Boyle, 2005; Waller et al., 2005; Reinhardt, 2007; Khan et al., 2011abc; Davitt et al., 2011). Previously, three different endophytic fungal strains (Aspergillus favus, Coniothyrium sp., and Nigrospora sp.) were isolated from pepper plant which improved plant growth and protected plants against pathogenic attack. However, we failed to find any report of phytohormones producing endophytic fungi from the isolated from pepper plants. GA-producing fungal endophytes might have potential to increase crop yields due to increasing concern about the excessive use of fertilizers in agricultural and the subsequent negative effect on the environment. In present work, we aimed to isolate phytohormones producing bioactive endophytic fungal strain from the roots of drought stressed pepper plants. We screened the
isolated strains through a dwarf GAs mutant rice line — Waito- C. The culture of the fungus was subjected to chromatic techniques to isolate and detect phytohormones.

Materials and Methods

Isolation of endophytic fungi: Roots were collected from pepper plants growing in drought stressed conditions. The soil characteristics during root sample collection were: 65% sand, 14.5% clay, 14.5% silt, 6.0% organic matter, pH 6.0-6.4, bulk density of 1.4gcm³ and moisture content 41.82 hPa. Roots were thoroughly washed with tap water and consecutively treated with 1% Tween 80 solution, 1% perchloric acid and autoclaved double distilled water (DDW) for 5 minutes in shaking incubator (120rpm) (Khan et al., 2011ab). The contaminants, rhizobacteria and mycorrhizal fungi were thus removed during surface sterilization. The endophytes were isolated as described by Waller et al., (2005) and Khan et al., (2011ab). Briefly, secondary root’s pieces (0.5 cm) were selected and carefully placed on Hagem medium plates (0.5% glucose, 0.05% KH₂PO₄, 0.05% MgSO₄.7H₂O, 0.05% NH₄Cl, 0.1% FeCl₃, 80ppm streptomycin and 1.5% agar; pH 5.6±0.2) to isolate endophytic fungal spots. The newly emerged fungal spots were separated under sterilized conditions and grown on potatosdextrose agar (PDA) medium plates for growth and storage (Khan et al., 2011a). Total eight different fungal strains were isolated and grown on PDA media. These strains were inoculated in Czapek broth (50 ml; 1% glucose, 1% peptone, 0.05% KCl, 0.05% MgSO₄.7H₂O, and 0.001% FeSO₄.7H₂O; pH 7.3±0.2) and grown for 7 days (shaking incubator -120 rpm; temperature 30°C) to separate liquid culture medium and fungal mycelia (centrifugation 2500g at 4°C for 15min). The culture medium (culture filtrate-CF, 50 ml) and mycelium (5.4gm) were immediately shifted to -70°C freezer and then freeze-dried (Virtils Freeze Dryer, Gardiner, NY, USA) for 4-7 days. The lyophilized CF was diluted with one ml of autoclaved DDW, while the mycelia were used for genomic DNA extraction.

Screening for phytohormone production: To assess plant growth promoting or inhibiting and phytohormones producing fungal isolate, the CF of endophytes were screened to determine their effect on mutant Waito-C rice growth. Waito-C rice is a gibberellin biosynthesis mutant line. Waito-C rice seeds were surface sterilized with 2.5% sodium hypochlorite for 30 minutes, rinsed with autoclaved DDW, and then incubated for 24 h with 20-ppm uniconazol to obtained equally germinated seeds. Germinated rice seeds (moisture content 71%; germination 95%) were transplanted to autoclaved pots containing 0.8% water-agar medium and kept in growth chamber (day/night cycle: 14 hr- 28°C±0.2; 10 hr- 25°C±0.2; relative humidity 70%; 18 seedlings per treatment) for further growth. After attaining two leaves stage, 10-µl of fungal CF was applied at seedling apex. One week after treatment, the shoot length, chlorophyll content and shoot fresh weight were recorded and compared with negative (autoclaved DDW) and positive controls (Fusarium fujikuroi). The wild-type strain of F. fujikuroi KCCM12329, provided by the Korean Culture Center of Microorganisms, was used as positive control. Upon screening results, bioactive fungal strain CAC-1G was selected for further experiments and identification.

DNA extraction and fungal isolate identification: Genomic DNA isolation and PCR was performed according to an established protocol (Khan et al., 2008). Fungal isolate was identified by sequencing the internal transcribed spacer (ITS) using universal primers ITS-1 (5´-TCC GTA GGT GAA CCT GCG G-3´) and ITS-4 (5´-TCC GCT TAT TGA TAT GC-3´) (Taylor & Bruns 1999). The BLAST search program (http://www.ncbi.nlm.nih.gov/BLAST) was used to compare the sequence homology of nucleotide of 18S ITS region of fungi. The closely related sequences obtained were aligned through CLUSTAL W using MEGA version 4 software (Tamura et al., 2007), and the maximum parsimony tree was constructed using the same software. The bootstrap replications (1K) were used as a statistical support for the nodes in the phylogenetree.

Phytohormones extraction, isolation and detection from bioactive CF: To extract, isolate and characterize GAs secreted in the pure fungal culture of bioactive endophyte, it was inoculated in Czapek broth (120 ml) for 7 days at 30°C (shaking incubator-120 rpm). The culture medium of F. fujikuroi and bioactive endophyte (CF; 50 ml) were used to extract and purify GAs as described by Hamayun et al., (2010). Briefly, the pH of the CF was adjusted to 2.5 using 6 N HCl and was partitioned with ethyl acetate (EtOAc). Before partitioning, deuterated GAs internal standards (20 ng; [17, 17-2H₂] GA₁, GA₃, and GA₁₂) were added in the CF. Tritiated GAs i.e. [1, 2-3H₂] GA₀ and [1,2-3H₂] GA₂₀ were also added (obtained from Prof. Lewis N. Mander, Australian National University, Canberra, Australia). The organic layer was vacuum dried and added with 60% methanol (MeOH) while the pH was adjusted to 8.0±0.3 using 2 N NH₄OH. Similarly, endogenous GAs from cucumber plants treated with and without endophytic fungus and salinity stress were extracted from 0.5 g of freeze-dried plant samples according to the method of Lee et al., [31]. The CF extract was subjected to chromatographic and mass spectroscopy techniques for identification and quantification of GAs. The dried samples were subjected to high performance liquid chromatography (HPLC) using a 3.9×300 m Bondapak C18 column (Waters Corp., Milford, MA, USA) and eluted at 1.0ml/min with the following gradient: 0 to 5 min, isocratic 28% MeOH in 1% aqueous acetic acid; 5 to 35 min, linear gradient from 28% to 86% MeOH; 35 to 36 min, 86% to 100% MeOH; 36 to 40 min, isocratic 100% MeOH. Forty-eight fractions of 1.0 ml each were collected. The fractions were then prepared for gas chromatography/mass spectrometry (GC/MS) with selected ion monitoring (SIM) system (6890N Network GC System, and 5973 Network Mass Selective Detector; Agilent Technologies, Palo Alto, CA, USA). For each GAs, 1-µl of sample was injected in
GLUCOSE, 1% PEPTONE, 0.05% KCl, 0.05% MgSO₄·7H₂O, 20 ml/pot of endophyte-free medium (containing 1% macro-nutrients present as: NH₄⁺ ~90 mg Kg⁻¹; NO₃⁻ (7-11%), coco-peat (63-68%) and zeolite (6-8%), with major ions of the supplemented [17-²H₂] GAs internal standards and the fungal GAs were monitored simultaneously whereas the same was done for endogenous GAs of cucumber plants. The fungal CF GAs were calculated from the peak area ratios of sample GAs to corresponding internal standards. The retention time was determined using hydrocarbon standards to calculate the KRI (Kovats retention index) value. The limit of detection was determined for all GAs. GC/MS SIM limit of detection was 40pg/ml for fungal CF. The data was calculated in nano-grams per milliliter (for fungal CF) and repeated three times.

The bioactive CF was assess for the presence of IAA with the help of High Performance Liquid Chromatography (HPLC) system, equipped with a differential ultraviolet (UV) detector absorbing at 280nm and a C18 (5µm; 25 x 0.46 cm) column. Mobile phase was methanol and water (80:20 [v/v]) at a flow rate of 1.5 ml/min. The sample injection volume was 10µl. Retention times for the analyte peaks were compared to those of authentic internal standards added to the medium and extracted by the same procedures used with fungal cultures. Quantification was done by comparison of peak area ratios of sample GAs with the help of High Performance Liquid Chromatography (HPLC) system, equipped with a differential ultraviolet (UV) detector absorbing at 280nm and a C18 (5µm; 25 x 0.46 cm) column. Mobile phase was methanol and water (80:20 [v/v]) at a flow rate of 1.5 ml/min. The sample injection volume was 10µl. Retention times for the analyte peaks were compared to those of authentic internal standards added to the medium and extracted by the same procedures used with fungal cultures. Quantification was done by comparison of peak area ratios of sample GAs to corresponding internal standards. The retention time was calculated from the peak area ratios of sample GAs to corresponding internal standards. The retention time was calculated using hydrocarbon standards to calculate the KRI (Kovats retention index) value. The limit of detection was determined for all GAs. GC/MS SIM limit of detection was 40pg/ml for fungal CF. The data was calculated in nano-grams per milliliter (for fungal CF) and repeated three times.

**Host-plant growth:** The pepper seeds were surface sterilized as described earlier and the germinated seeds (28°C and relative humidity of 60%) were sown in autoclaved soil (200 g/pot of soil at 121°C for 90 min). The soil characteristics were: peat moss (13-18%), perlite (7-11%), coco-peat (63-68%) and zeolite (6-8%), with macro-nutrients present as: NH₄⁺~90 mg Kg⁻¹; NO₃⁻~205 mg Kg⁻¹; P₂O₅~350 mg Kg⁻¹ and K₂O~100 mg Kg⁻¹. The culture medium (20 ml/pot) along with the propagules (10) of bioactive endophyte was applied to the area (Shahab et al., 2009).

**Results**

**Screening of plant hormone secreting bioactive endophyte:** We isolated 13 endophytic fungi from 31 different secondary roots of three pepper plants. These endophytic fungi were grown on Hegam minimal media for seven days. The frequency of endophyte isolation was 2.34. However, upon morphological trait analysis of 13, only eight were different on the basis of colony shape, height and color of aerial hyphae, base color, growth rate, margin characteristics, surface texture and depth of growth into medium (Arnold et al., 2007). The CF of these endophytes were screened on dwarf Waito-C rice seedlings. The results showed that four fungi exhibited growth stimulatory effects and 3 strains exhibited inhibitory effects as compared to both DDW and *F. fujikuroi* treated rice seedlings (Table 1). In growth promotive strains, endophyte CAC-1G significantly increased the shoot length, shoot fresh weight, chlorophyll content and leaf area of pepper plants as compared to other endophytic CF and controls. In inhibitory strains, the CF of CAC-1A significantly suppressed the growth attributes of Waito-C rice seedlings as compared to control (Table 1).

### Table 1. Effect of CF of endophytic fungal strains isolated from the roots of field grown cucumber plants on the growth of *Waito-C* rice seedlings.

<table>
<thead>
<tr>
<th>Strains</th>
<th>TL (cm)</th>
<th>SL (cm)</th>
<th>CC (SPAD)</th>
<th>FW (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (Ff)</td>
<td>15.5 ± 0.29c</td>
<td>9.4 ± 0.32b</td>
<td>34.3 ± 1.4c</td>
<td>0.63 ± 0.19b</td>
</tr>
<tr>
<td>Control (DW)</td>
<td>13.25 ± 0.25d</td>
<td>7.2 ± 0.31d</td>
<td>32.87 ± 1.7d</td>
<td>0.61 ± 0.13b</td>
</tr>
<tr>
<td>CAC-1C</td>
<td>12.73 ± 0.37d</td>
<td>7.4 ± 0.21d</td>
<td>30 ± 0.58e</td>
<td>0.47 ± 0.11d</td>
</tr>
<tr>
<td>CAC-1G</td>
<td>18.26 ± 0.15a</td>
<td>11.5 ± 0.35a</td>
<td>40.8 ± 1.7a</td>
<td>0.71 ± 0.10a</td>
</tr>
<tr>
<td>CAC-1J</td>
<td>15.8 ± 0.32b</td>
<td>9.46 ± 0.29b</td>
<td>38.6 ± 1.1b</td>
<td>0.61 ± 0.12b</td>
</tr>
<tr>
<td>CAC-1F1</td>
<td>15.43 ± 0.44c</td>
<td>8.7 ± 0.31c</td>
<td>32.6 ± 1.36d</td>
<td>0.56 ± 0.18c</td>
</tr>
<tr>
<td>CAC-1E</td>
<td>14.2 ± 0.56d</td>
<td>8.46 ± 0.24c</td>
<td>35.13 ± 1.8c</td>
<td>0.59 ± 0.14c</td>
</tr>
<tr>
<td>CAC-1A</td>
<td>14.6 ± 0.42c</td>
<td>8.16 ± 0.55c</td>
<td>33 ± 1.11d</td>
<td>0.57 ± 0.22c</td>
</tr>
<tr>
<td>CAC-1H</td>
<td>14.46 ± 0.74c</td>
<td>8.33 ± 0.74c</td>
<td>35.8 ± 1.2c</td>
<td>0.55 ± 0.12c</td>
</tr>
<tr>
<td>CAC-IK</td>
<td>16.27 ± 0.67b</td>
<td>9.93 ± 0.33b</td>
<td>38.8 ± 1.6b</td>
<td>0.66 ± 0.14b</td>
</tr>
</tbody>
</table>

Control (Ff) = rice seedlings treated with the CF of a Wild-type strain of *F. fujikuroi* KCCM12329; Control (DW) = rice seedlings treated with autoclaved distilled water. SPAD = Soil plant analysis development. TL = total length; SL = shoot length; CC = chlorophyll content; FW= fresh weight. In each column, treatment means having different letter(s) are significantly (p<0.05) different as evaluated by DMRT. Values are mean ± SD (n=18).
CAC-1G identification and phylogenetic analysis: Phylogenetic analysis of the ITS sequence of CAC-1G was carried out through Mega 4.0 using maximum parsimony (MP) method to make a consensus tree from 15 (14 references and 1 clone) aligned ITS1 and ITS4 with 1,000 bootstrap replications. Results of BLASTn search revealed that sequence of fungal strain CAC-1G has 100% sequence similarity with Chaetomium globosum. In MP dendrogram, CAC-1G formed 63% bootstrap support with C. globosum (Fig. 1). On the basis of sequence similarity and phylogenetic analysis, fungal isolate CAC-1G was identified as C. globosum LK4. The 18S rDNA sequence was submitted to NCBI GenBank and was given accession no. JQ288106.

GAs and IAA secretion by C. globosum LK4: The pure culture filtrate of C. globosum LK4 was analyzed for the presence of GAs and IAA. In GAs extraction, isolation and detection, we found that the CF of C. globosum had five different physiologically active and non-active gibberellins (Fig. 2). The GAs was detected through GC/MS selected ion monitor. Among biologically active GAs, GA1 (0.67±0.13 ng/ml) and GA4 (21.8±1.2 ng/ml) were found in the HPLC fractions. In physiologically inactive GAs, GA9 (0.51±0.11 ng/ml), GA12 (13.4±0.41 ng/ml), GA20 (1.11±0.2 ng/ml) and were present in the CF. The quantities of bioactive GA4 and GA12 were significantly higher as compared to other GAs (Fig. 2). In the culture of F. fujikuroi, we found bioactive GA3 (12.4±1.03 ng/ml) and GA4 (3.1±0.4 ng/ml), GA9 (0.8±0.21 ng/ml), GA12 (13.1±1.11 ng/ml), GA20 (0.95±0.31 ng/ml). Besides GAs, we also found IAA in the growing culture medium of C. globosum. The quantity of IAA was 16.71±1.42 µg/ml.

Effect of C. globosum on host-plant growth: The C. globosum inoculation to the host pepper plants significantly increased the shoot length as compared with the endophyte-free medium and water applied control plants. Similarly, the chlorophyll content, leaf area and shoot biomass were also significantly higher in plants inoculated with C. globosum as compared to control plants (Fig. 3).

Discussion

Increase in human population has exerted tremendous pressure on agriculture land to obtain higher crop productivity and satisfy the food demand. To avoid continuous depletion of natural resources and achieve goals of sustainable agriculture development, various eco-friendly alternatives are available. Among them, symbiotic fungal associations with crops show considerable promise because of their effectiveness, habit-specific mode of action and ability to provide multiple benefits (Schulz & Boyle, 2005; Diene and Narisawa, 2009; Lamit and Gehring, 2012; Rodriguez et al., 2012). Endophytes have been presumed as one of the future resources for increasing crop productivity and alternative to synthetic chemicals (Diene & Narisawa, 2009). A plant endophytic fungus produces many natural bioactive compounds with dominant importance in agriculture, medicine and food industry (Schulz & Boyle, 2005; Zhao et al., 2010; Khan et al., 2011abc). In the present study, we isolated an endophytic fungus from the roots of drought stressed pepper plants. It was identified as a strain of C. globosum LK4 by sequencing the 18S rDNA regions. Chaetomium is a large genus of the fungal family Chaetomiaceae (Ascomycota) with over an hundred marine- and terrestrial-derived species. To date, more than 200 compounds have been reported from this genus (Li et al., 2011). Previously, endophyte C. globosum has been isolated from various economically important plants like Ginkgo biloba (Li et al., 2011). From C. globosum a verity of bioactive secondary metabolites have been isolated and identified as reported by Qin et al., (2009) and Li et al., (2011). However, in present study we unveiled the phytohormone production capacity of this endophyte.
Previously, reports are available which elaborate the GAs and auxins secretion by endophyte (Hamayun et al., 2010; Khan et al., 2011abc). Gibberellins are the most important phytohormones and play an essential role in plant growth and development (Bomke & Tudzynski, 2009). In present study, we found that endophyte C. globosum produces various physiologically active and in-active GAs in its culture medium. It was observed that the CF of C. globosum significantly promotes the growth attributes of mutant rice Waito-C. Dwarf rice (Waito-C) is GAs biosynthesis mutant line having passive dy gene which synthesize bioactive GAs through C13 hydroxylation pathway (Ikada et al., 2001). The Waito-C rice seeds were treated with uniconazol to further suppress the GAs biosynthesis pathway (Ikada et al., 2001). The use of Waito-C rice can help in detection of a very small amount of GAs if present in the sample (Hamayun et al., 2010; Khan et al., 2011a). Agar and water, on the other hand, was used as growing medium for rice. During the bioassay, the rice seeds were devoid of any nutrients to accurately measure the sole effect of fungal CF (Soon-Ok et al., 2007). Fusarium fujikuroi corresponds to the mating group C of Fusarium fujikuroi and has the ability to produce GAs on industrial level (Takahashi et al., 1991). We compared the effect of CF of Wild type F. fujikuroi with that of C. globosum and found a similar growth promoting behaviour. The further comply the findings, CF of both C. globosum and F. fujikuroi were analyzed for GAs production through GC MS/SIM which is an established method to identify targeted novel secondary metabolites (Higgs et al., 2001). The repetition of our experiment and correlation with GAs detection in corresponding to deuterated GAs standards further helped to confirm our findings of GAs production. Several researchers reported the plant growth promoting characteristics and secretion of secondary metabolites including phytohormones of endophytic fungi mostly associated with roots (Rademacher, 1994; Kawaide, 2006; Khan et al., 2011abc). In the CF, we found GA$_4$, though the quantity of GA$_4$ was very low. In fungus, GA$_{12}$-aldehyde is 3b-hydroxylated to GA$_{14}$-aldehyde and then oxidized to form GA$_{14}$. The subsequent conversion of GA$_{14}$ to GA$_{4}$ is comparable to the production of GA$_{9}$ and GA$_{20}$ in plants. Desaturation of GA$_{4}$ results in the formation of GA$_{7}$ and then GA$_{3}$, which is the main product reported from F. fujikuroi (Bomke & Tudzynski, 2009; Khan et al., 2012). The endophyte also produced IAA in its culture medium. The presence of IAA in C. globosum
clearly suggests the existence of IAA biosynthesis pathway as reported for some other classes of fungi by Tuomi et al., (1993).

Endophytic mutualism can extend beneficial growth regulatory effects on host-plant under normal as well as extreme environmental conditions. In current study, the C. globosum has significantly increased the shoot growth and allied growth characteristics of the host pepper plants. The plant had higher chlorophyll content, shoot biomass and leaf area compared to both the controls, indicating growth ameliorative impacts on plants. In endophyte-host symbioses, secondary metabolites may be a contribution of the endophytic partner for such mutualistic relationship. Plants treated with endophytes are often healthier than those lacking such interaction (Schulz & Boyle, 2005), which may be attributed to the endophyte secretion of phytohormones such as IAA (Khan et al., 2011b) and GAs (Rademacher, 1994; Bomke et al., 2008; Kawaiide, 2006; Hamayun et al., 2010). As such the practical applications of endophytes as potential sources of bioorganic nutrients and as biocontrol agents can significantly improve yields in eco-friendly method (Diene & Narisawa, 2009; Khan et al., 2012; Naz and Bano, 2012). Understanding such endophytic interactions can therefore help to improve the quality and productivity of agricultural crops.

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References

ISOLATION AND DETECTION OF GIBBERELLINS AND INDOLE ACETIC ACID


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