

### EXPLORING THE BENEFICIAL ENDOPHYTES OF ZINGIBERACEAE

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#### Review

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#### ABSTRACT

Sustainable agriculture in combination with crop improvement programme is gaining more attention in the scientific field nowadays. With abundance of resources, endophytes offer an environmentally friendly and sustainable approach to increase crop yield, improve soil fertility while protecting the plants from a number of biotic and abiotic stresses. Residing within plant, endophytes are unique group of symbionts that systematically invade the internal environment of host without causing any pathogenic symptoms. Endophytes, which include bacteria, fungi, and viruses, have been shown to have beneficial effects on their hosts, either directly or indirectly. On the other hand, Zingiberaceae is a valuable family of ginger that has a lot of economic benefits. Endophytes isolated from the Zingiberaceae plants are known to promote plant development through the production of phytohormone, 1- aminocyclopropane -1 carboxylic acid (ACC) deaminase, siderophore and also assist the host plant in phosphate solubilization activity. They are also prominent producers of several secondary metabolites with a lot of bioactivities. However, the full potential of endophytes from the Zingiberaceae plants largely remain untapped. Thus, the aim of this review is to discover various types of endophytes isolated from the Zingiberaceae plants, their phytohormone production, nutrient acquisition, biohardening application, secondary metabolites production and bioactivities. The broad knowledge of endophytes from Zingiberaceae plants will provide insight into new economic potentials and determine its future in sustainable agriculture practices.

**Keywords:** Bioactivity, Biohardening, Endophytes, Phytohormone, Phytochemicals, Sustainable agriculture

#### INTRODUCTION

Plants are recognized as metaorganisms that possess a distinct microbiome and close symbiotic relationships with associated microorganisms where these systems play an important role in regulating an ecosystem's biological cycle while ensuring agricultural sustainability (Badri *et al.*, 2009). The important symbiont in the plant-microbe interactions is a group of microbes called endophytes. Endophytes are the microbial system that is capable of influencing and interacting with host plant metabolic processes (Kanani *et al.*, 2020). Endophytes can be defined as an endosymbiotic group of organisms which include bacteria, fungi, and viruses that colonize the host plant without causing any apparent symptom of diseases (Jha *et al.*, 2023; Wen *et al.*, 2023).

Endophytes have been considered as important plant partners for their major contributions in plant growth. They promote plant growth through the production of several phytohormones such as auxin, cytokinin, gibberellins and ethylene (Taghavi *et al.*, 2009; Maheshwari *et al.*, 2020). Production of indole-3-acetic acid (IAA), an auxin helps in promoting immediate responses such as cell elongation as well as long-term responses such as cell differentiation (Spaepen *et al.*, 2007; Taghavi *et al.*, 2009). Endophytes also have the capability to exhibit other properties like production of siderophores and 1-aminocyclopropane-1 carboxylic acid (ACC) deaminase. Siderophores are iron-chelating substances released by certain microbes during low iron levels. Siderophores-producing bacteria have drawn more interest during the last two decades due to their contribution in plant growth and protection. These microbes are believed to enhance iron uptake and inhibit the growth of other phytopathogens by releasing antibiotics and limiting the iron availability for pathogens (Ghavami *et al.*, 2017). Equally important, ACC deaminase production is one of the mechanisms by endophytes to help plants survive under ethylene stress (Maheshwari *et al.*, 2020). Endophytes are also capable of solubilizing insoluble phosphate into soluble form that enhances the phosphorus uptake by the plants (de Freitas *et al.*, 1997). Furthermore, endophytes have been shown to produce secondary metabolites with antibacterial and antifungal properties that aid in the inhibition of pathogen growth (Gunatilaka, 2006). For instance, endophytic bacteria from *Alpinia galanga* roots synthesize antifungal and antibacterial substances such as kaempferol and isocutellarin that are known to have strong activity against pathogens such as *Bacillus subtilis* and *Staphylococcus aureus* (Taechowisan *et al.*, 2008).

Moreover, Zingiberaceae is one of the well documented families with a lot of economic benefits. This family comprises of 53 genera and over 1300 species (John Kress *et al.*, 2002). The primary genera of this family are *Zingiber* (49 spp.), *Kaempferia* (17 spp.), *Hedychium* (22 spp.), *Curcuma* (34 spp.), *Globba* (42 spp.), *Alpinia* (17 spp.), *Amomum* (16 spp.), *Etingera* (12 spp.), and *Caulokaempferia* (14 spp.) (Rachkeeree *et al.*, 2018). These fragrant flowering plants can be found throughout tropical Africa, Asia, and the Americas (Pitopang *et al.*, 2019). This family has been used traditionally for food and flavorings due to its strong aroma especially in Southeast Asia (Verma, 2018; Zhou *et al.*, 2018; Yunus *et al.*, 2021). Additionally, Zingiberaceae plants are rich in phytochemicals such as alkaloids, phenolic acids, flavonoids, and diarylheptanoids which can be used to produce many downstream products like essential oils, medicines, dyes, perfume, and aesthetics (Ashokkumar *et al.*, 2020; Yunus *et al.*, 2022).

However, there is lack of information about the endosymbiotic microbes related to the entire Zingiberaceae family. Extensive information on endophytes will comprehend the nature of the microbiome with the Zingiberaceae family. Therefore, the purpose of this review is to examine the various types of endophytes from the Zingiberaceae plants, research on IAA phytohormone production, nutritional acquisition, biohardening application, secondary metabolites, and bioactivities of these valuable microorganisms. This review seeks to discuss enormous potentials of the endophytes and why this group of microorganisms is a perfect candidate for commercialization.

#### ENDOPHYTES INVASION MECHANISMS

Endophytes invade plant hosts by engaging in complex chemical interactions with roots and soil microorganisms. The process begins with the root exudation and followed by the recognition of certain biochemical molecules in the root exudates by endophytes (Rosenblueth & Martínez-Romero, 2006) (Fig 1). Biochemical compounds of the plant root exudates contain primary and secondary metabolites, including organic acids, amino acids, alcohols, sugars, polyamines, purines, fatty acids, phytohormones, flavonoids, terpenoids, and benzoxazinoids. Besides, plants exude 11–40% photosynthetically fixed carbon where it creates chemical gradients in the rhizosphere. These root exudates act as chemo-attractants for endophytes migration from the soil to the root surface (Malfanova *et al.*, 2013; Mengistu, 2020). Attachment of the endophytes to the root surface occurs in biphasic processes. First, primary attachment causes reversible weak adherence of single cells to the root surface, assisted by electrostatic and hydrophobic interactions. This

species-specific surface adhesins and proteinaceous appendages make the attachment stronger (Knights et al., 2021). The success of primary attachment leads to the second phase of attachment where it is characterized by strong and permanent bacterial attachment to the root surface. Endophytes penetrate the plant root after becoming established on the rhizoplane either through active or passive process. The endophytes can passively penetrate the root tissue through lateral root emergence and wounds (Hallmann, 2001; Hardoim et al., 2008). For active penetration, Böhm et al. (2007) revealed that twitching motility of the bacteria influences the movement of endophytes inside the host. Furthermore, endophytes penetrate and inhabit the roots by releasing enzymes particularly pectinases and cellulases that dissolve the cell walls (Compant et al., 2005).

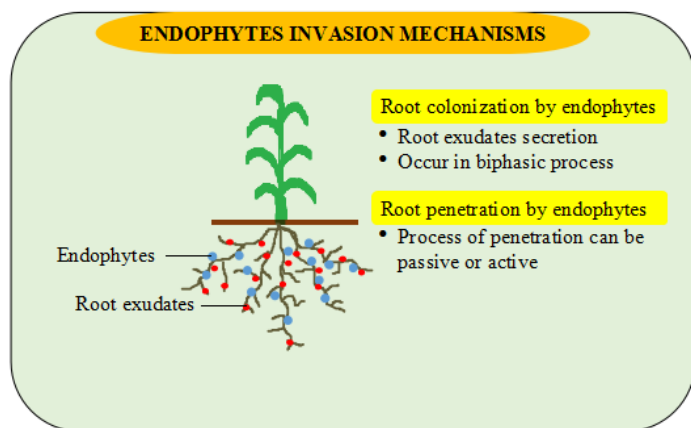


Figure 1 Endophytes invasion mechanisms

## ENDOPHYTES AS PLANT GROWTH PROMOTER IN ZINGIBERACEAE

Endophytes directly give benefits to the plants by modulating growth related hormones and assisting plants in getting nutrients, which can help plants to grow better under normal and stressed conditions (Ma et al., 2016). Indirectly, endophytic bacteria improve plant's growth by discouraging phytopathogens using mechanisms such as antibiotic and lytic enzyme production, reduces the nutrient availability for the pathogens, and activates defense systems in plants (Miliute et al., 2015).

### Phytohormone production

Plant hormones are classified into five types, namely gibberellins, ethylene, abscisic acid, cytokinin and auxin, where ethylene and IAA (a form of auxin) are common in plant-microbial interactions (Afzal et al., 2019). Generally, endophytes can improve host plants' nutrition uptake and metabolism by releasing growth-regulating phytohormones.

Due to its important role in plants, endophytic production of IAA has gained great attention from plant scientists (Matsuda et al., 2005). IAA is a significant hormone which participates in a variety of physiological activities in plants. These include the induction of plant defense mechanisms, control of plant development, and cell-signaling (Gravel et al., 2007; Spaepen et al., 2007). IAA also helps instigate the formation of lateral and adventitious roots, biosynthesis of metabolites, photosynthesis, mediate responses on stimuli, and stress conditions (Glick, 2012). Furthermore, IAA also assists in controlling production of plant hormones such as ethylene (Woodward & Bartel, 2005; Glick, 2012). Additionally, IAA can boost surface area and plant root biomass while increasing lateral root formation in host plants (Dias et al., 2008, Taghavi et al., 2009).

Previous studies have successfully identified IAA-producing bacteria from *Curcuma longa*. Kumar et al. (2016) reported that a few genera of bacteria isolated from *C. longa* including *Bacillus pumilus*, *Bacillus thuringiensis*, *Bacillus cereus*, *Clavibacter michiga* and *Pseudomonas putida*, have potential to synthesize IAA. Additionally, Vinayarani and Prakash (2018b) stated that *Pseudomonas aeruginosa*, *Enterobacter* sp. and *Acinetobacter* sp. isolated from *C. longa* were able to produce IAA. Moreover, Aswathy et al. (2012) postulated that the bacterium *Paenibacillus* sp., isolated from the rhizome of *C. longa*, has the potential to synthesize IAA and has been shown to improve plant growth.

Several researchers managed to isolate IAA producing bacteria from *Zingiber officinale*. For instance, Jasim et al. (2013) stated that *Pseudomonas* sp. isolated from *Z. officinale* is an IAA producing bacterium. Another study revealed that 19 endophytic bacteria were found to have the ability to produce IAA and assist plant growth. These bacteria include *Agrobacterium larrymoorei*, *Stenotrophomonas maltophilia*, *Acetobacter pasteurianus*, *Pantoea ananatis*, *Serratia nematodiphila*, *P. putida*, and *Leclercia adecarboxylata* (Chen et al., 2014). Zhang et al. (2018) revealed that 14 out of 57 endophytic bacteria isolated from *Z. officinale* rhizome were found to be capable of synthesizing IAA. These IAA producing bacteria were identified from the genus of *Tetrathiobacter*, *Enterobacter*, *Stenotrophomonas*,

*Pseudomonas*, *Acinetobacter*, *Serratia*, *Agrobacterium*, *Bacillus*, and *Ochrobactrum*.

Apart from auxin, ethylene is also necessary for controlling plant responses to biotic and abiotic stresses. It regulates a variety of physiological and developmental processes, including abscission, root initiation, root nodulation, leaf senescence, cell elongation, auxin transport and fruit ripening (Sun et al., 2015). During biotic and abiotic stresses, high amount of ethylene synthesized by plants caused inhibition of root elongation, formation of root hair and development of lateral roots. To overcome this issue, endophytic bacteria synthesize an enzyme called ACC deaminase which hydrolyze ACC, a precursor for ethylene biosynthesis. According to Sun et al. (2009), ACC degrading bacteria will adhere to plant roots and cleave the secreted ACC into  $\alpha$ -ketobutyrate and ammonia where ammonia will be used as a nitrogen source. As a result, ACC hydrolysis can decrease stress of the plant while promoting plant growth (Santoyo et al., 2016). There have been several reports on plant growth promoting endophytic bacteria that boost the ACC deaminase activity (Nikolic et al., 2011). Blaha et al. (2006) reported that many members of the genera *Enterobacter*, *Pseudomonas*, *Ralstonia*, *Burkholderia*, *Achromobacter*, *Agrobacterium*, *Azospirillum* and *Rhizobium* along with other various endophytic strains, produce ACC deaminase. A study found that some *Pseudomonas* sp. strains associated with *Z. officinale* produce ACC deaminase, which reduce the ethylene-inducing stresses and promote plant development (Jasim et al., 2013). Ethylene-mediated plant growth inhibition decreases as ACC and ethylene levels decrease. Hence, endophytic microbes promote plant growth by reducing the ethylene-inducing stresses (Glick et al., 2007; Hardoim et al., 2008).

### Nutrient acquisition

Soils frequently lack adequate amounts of the nutrients required for plant growth. Interestingly, endophytes can assist their host plants in obtaining higher amounts of limiting nutrients such as phosphorus and iron (Glick, 2012). Phosphorus is a macronutrient essential for the enzymatic reactions responsible for many plants' physiological processes. Unfortunately, around 75% of phosphorus applied as fertilizer, forms complexes with soil and becomes unavailable for the plants (Ezawa et al., 2002). According to Nautiyal et al. (2000), endophytic bacteria can increase phosphorus availability for plants by solubilizing precipitated phosphates through mechanisms such as acidification, chelation, ion exchange, and organic acid production. Endophytes increase phosphorus availability in the soil by secreting acid phosphatase that can mineralize organic phosphorus (Van Der Heijden et al., 2008). The ability to solubilize phosphate is frequently present in endophytic bacteria. For example, endophytic bacteria like *P. putida*, *Bacillus pumilus* and *B. cereus*, which are found in the roots and rhizosphere of the *C. longa*, stimulate the availability of phosphate to enhance plant growth (Kumar et al., 2016). Other than that, Anisha et al. (2013) demonstrated that the strain of *Klebsiella* sp., present in the rhizome of *C. longa*, can improve the growth of the plant by converting insoluble phosphate into soluble form. This is in line with the research by Bussaban et al. (2001) which claimed that endophytes isolated from *Amomum siamense* assist the absorption of the nutrients from the soil, such as phosphorus and other necessary molecules.

Most organisms require iron as an essential nutrient where many iron-containing proteins control important physiological processes such as respiration and transpiration (Ma et al., 2016). Iron is commonly found in the insoluble ferric ( $Fe^{3+}$ ) form, which is almost inaccessible to most plants. Interestingly, endophytes produce siderophores which bind to insoluble ferric ions (Ma et al., 2011). As a result, plants are able to gain iron from these bound siderophores by ligand exchange or chelate breakdown at the root level (Rajkumar et al., 2009; Ma et al., 2016). For example, endophytic bacterium of *P. putida* isolated from *C. longa* was able to synthesize siderophore and defend itself against pathogenic microorganisms (Kumar et al., 2016). Vinayarani and Prakash (2018b) reported that the production of siderophore protects *C. longa* against rot and leaf blight diseases caused by *Rhizoctonia solani* and *Pythium aphanidermatum*. Furthermore, Jasim et al. (2013) demonstrated that different species of *Pseudomonas* and *Stenotrophomonas* have the capability to produce siderophore in the root of *Z. officinale*. In short, endophytes have the economic potential to develop into more environmentally friendly biofertilizer.

### BIOHARDENING

Biohardening, also known as biopriming, is a technique using microbial inoculants especially bacteria, either on *in vitro* plantlets or seedlings to increase plant growth (Divya et al., 2022). For the *in vitro* grown plantlets, the transition from *in vitro* to *ex vitro* conditions is a vital stage in micropropagation where the high risk of mortality happened due to the shock of transitory transplant during the transfer of plantlets. Most *in vitro* plantlets have a problem with stunted growth, easily attacked by soil-borne microbes and lack of ability to withstand the natural environment (Divya et al., 2022). Biohardening signifies the role of microbial inoculants as propagule priming agents for *in vitro* cocultures and on transplanting process (Nowak & Pruski, 2002). The biohardened plants respond more promptly and efficiently than non-biohardened plants upon exposure to stress (Conrath et al., 2002). This will improve several economically significant horticulture crops'

resilience to plant diseases (Sharma & Nowak, 1998; Ait Barka et al., 2002). Divya et al. (2022) mentioned that *Piriformospora indica*, an endophytic fungus isolated from root, has been utilized as a potential agent for biohardening in tissue culture plantlets. Bajaj et al. (2014) demonstrated that *ex vitro* co-cultivation of *C. longa* with *P. indica* resulted in higher yield and enhanced the curcumin and volatile oil production. In future, *P. indica* could be used to bioharden and support the growth of the micropropagated plant from other species. This statement is supported by a study from Sahay and Varma (1999) where the researchers proved that tobacco plantlets grown in tissue culture supplemented with *P. indica* have higher plant biomass, better root growth, and survival rates.

**SECONDARY METABOLITES AND BIOACTIVITIES OF ENDOPHYTES IN ZINGIBERACEAE**

Endophytes are known for their ability to produce numerous secondary metabolites with a broad range activity against pathogenic microorganisms (Al-Shaibani et al., 2016). Substance for self-defence produced by the endophytes in the competitive environments help to defence itself against biotic and abiotic stresses. Some examples of the secondary metabolites and biological activities produced by the endophytes found in the Zingiberaceae plants are presented in Table 1.

**Table 1** Secondary metabolites and/or biological activities of endophytes in Zingiberaceae

Plant organ	Plant Growth Promoting Endophytes	Secondary metabolites and/or biological activities	References
<i>Alpinia galanga</i> roots.	<i>Streptomyces</i> sp. Tc052 (bacterium).	The endophytic bacterium synthesized secondary metabolites that have antifungal and antibacterial activities substances such as kaempferol, isocutellarin, umbelifirone and cichoriin. Kaempferol and isocutellarin showed strong activity against <i>Staphylococcus aureus</i> and <i>B. subtilis</i> . Moderately effective towards <i>E. coli</i> and <i>P. aeruginosa</i> . Kaempferol, isocutellarin and umbelifirone showed better protection against <i>Candida albicans</i> , a pathogenic yeast, while cichoriin showed no activity.	(Taechowisan et al., 2008)
<i>A. galanga</i> roots.	<i>Streptomyces</i> sp. (bacterium).	<i>Streptomyces</i> sp. LJK109 showed promising inhibitory effects. Compound analysis revealed the presence of 3-methylcarbazole and 1-methoxy-3-methylcarbazole. The growth of phytopathogenic fungi from numbers of species has been tested. For both compounds, inhibition of mycelium extensions was proven on <i>Sclerotium rolfsii</i> , <i>Verticillium</i> sp, <i>Fusarium oxysporum</i> , <i>Exserohilum</i> sp, <i>Drechslera</i> sp, <i>Curvularia</i> sp, <i>Colletotrichum musae</i> , <i>Alternaria porri</i> , and <i>Colletotrichum gloeosporioides</i> . Compound 3-methylcarbazoles showed antifungal activities through inhibition of mycelium extension and conidia germination. This compound can be investigated on human pathogenic fungi like <i>C. albicans</i> and <i>Cryptococcus neoformans</i> .	(Taechowisan et al., 2012)
<i>Boesenbergia rotunda</i> roots.	<i>Streptomyces</i> sp. BO-07 (bacterium).	Two biphenyl compounds; 3'-hydroxy-5-methoxy-3,4-ethylenedioxybiphenyl and 3'-hydroxy-5,5'-dimethoxy-3,4- methylenedioxybiphenyl have been extracted. Antioxidant activities were shown by these two compounds. Both compounds proved to have antibacterial activities against <i>S. aureus</i> , <i>B. cereus</i> and <i>B. subtilis</i> . Anticancer activities were proved through investigation on human cervical carcinoma cell line, human liver carcinoma cell line, and human hepatoma cell line.	(Taechowisan et al., 2017)
<i>Curcuma longa</i> leaves.	<i>Penicillium</i> sp. (fungus).	Silver nanoparticles (AgNPs) were synthesized through manipulation of the fungus, where it can be used as a metal reducing agent. AgNPs, exhibited antibacterial activity on <i>P. aeruginosa</i> and <i>Klebsiella pneumoniae</i> .	(Singh et al., 2013)
<i>C. longa</i> rhizome.	<i>Pseudomonas aeruginosa</i> Bac- DOB-E19 (bacterium).	<i>In vitro</i> antagonistic dual culture test and greenhouse severity analysis were conducted. The results showed that the bacteria can be manipulated as a biocontrol agent against <i>Pythium aphanidermatum</i> and <i>R. solani</i> , both are pathogens that caused rhizome rot and leaf blight.	(Vinayarani & Prakash, 2018b)
<i>C. longa</i> rhizome.	<i>Trichoderma harzianum</i> TharDOB-31 (fungus).	Antagonism analysis through antagonistic dual culture and greenhouse severity experiment were examined. The fungal showed that it has biocontrol potential against <i>P. aphanidermatum</i> and <i>R. solani</i> via inhibition of mycelial growth.	(Vinayarani & Prakash, 2018a)
<i>Curcuma xanthorrhiza</i> leaves.	<i>Xylaria</i> sp. (fungus).	Two new secondary metabolites have been identified. Molecular formula of compound 1 is C <sub>17</sub> H <sub>16</sub> O <sub>6</sub> while compound 2 is C <sub>23</sub> H <sub>24</sub> O <sub>7</sub> . Plus, resacetophenone also has been detected.	(Hammerschmidt et al., 2015)
<i>Kaempferia rotunda</i> rhizome.	<i>Aspergillus flavus</i> (fungus).	The fungus secreted many secondary metabolites such as myricetin, kaempferol, ellagic acid, syringic acid, ferulic acid, coumarin acid, and caffeic acid. Through disk diffusion assay, inhibition of different strains of bacteria; <i>S. aureus</i> , <i>E. coli</i> , <i>K. pneumoniae</i> , <i>Bacillus</i> and <i>Enterococcus</i> were reported using fungal extract. Nematicidal activity test showed that the fungal extract caused lethality to <i>Haemonchus contortus</i> .	(Krishnakumar et al., 2021)
<i>Zingiber cassumunar</i> leaves.	<i>Arthrinium</i> sp. MFLUCC16-1053 (fungus).	The fungus synthesized multiple compounds such as $\gamma$ -curcumene, $\beta$ -isocumene, cembrene, 6E-farnesol, 2Z, sclareol, 3E-cembrene A, laurenan-2-one and $\beta$ -cyclocitral. The extract of the fungus successfully inhibits the growth of <i>S. aureus</i> and <i>E. coli</i> .	(Pansanit & Pripdeevech, 2018)
<i>Zingiber griffithii</i> rhizome.	<i>Hypomontagnella monticulosa</i> strain Zg15SU (fungus).	Extracted compounds were identified as griffithiine and scalarial. Antibacterial test proved that it has the antibacterial properties against <i>S. aureus</i> , <i>E. coli</i> , methicilin-resistant <i>S. aureus</i> , and enteropathogenic <i>E. coli</i> .	(Lutfia et al., 2021)
<i>Z. officinale</i> leaves	<i>Trichoderma harzianum</i> (fungus).	The fungus produced harzianic acid and isoharzianic acid compounds. Isoharzianic acid extract analysis showed it has antifungal effects towards <i>Ustilago maydis</i> and antibacterial activity against <i>S. aureus</i> .	(Harwoko et al., 2021a)
<i>Z. officinale</i> rhizome.	<i>Gliocladiopsis</i> sp., <i>Fusarium oxysporum</i> and unknown fungal sp. (GFV1) (fungi).	<i>Gliocladiopsis</i> sp. fungi secreted ergosta-4, 6, 8(14), 22-tetraen-3-one (ergone) compound. It showed maximum inhibition of <i>Pythium myriotylum</i> , a soft rot pathogen through dual culture technique. GFV1 produced tyrosol compound. Antibacterial effects were shown against <i>S. aureus</i> and <i>B. subtilis</i> by <i>F. oxysporum</i> and GFV1.	(Anisha & Radhakrishnan, 2017)

Continue Table 1			
<i>Z. officinale</i> roots, stems, tubers, and leaves.	<i>Bacillus</i> sp. and genus <i>Pseudomonas</i> sp. (bacteria).	Growth analysis on <i>P. myriotylum</i> , a pathogenic oomycete has been inhibited by <i>B. cereus</i> , <i>B. methylotrophicus</i> , and <i>B. amyloliquefaciens</i> . The pathogenic agent that caused soft rot disease was also inhibited by <i>P. aeruginosa</i> and <i>P. monteilii</i> .	(Chen et al., 2014)
<i>Z. officinale</i> (red ginger) root, stem and shoot.	<i>Curvularia affinis</i> , <i>Fusarium solani</i> , <i>Glomerella cingulate</i> (fungi).	Via antagonism assay, <i>C. affinis</i> , <i>F. solani</i> , and <i>G. cingulata</i> proved to inhibit colonization of <i>F. oxysporum</i> .	(Ginting et al., 2013)
<i>Z. officinale</i> rhizome.	<i>Nocardiopsis</i> sp. (actinomycete).	Phenol, 2,4-bis (1,1-dimethyl-ethyl) and trans cinnamic acid were secreted by the <i>Nocardiopsis</i> sp. The actinomycete crude extract showed to inhibit the growth of <i>P. myriotylum</i> . Well diffusion test showed that the crude extract was efficient to inhibit <i>Phytophthora infestans</i> , <i>Colletotrichum acutatum</i> , <i>F. oxysporum</i> , <i>Corynespora cassiicola</i> and <i>R. solani</i> .	(Sabu et al., 2017)
<i>Z. officinale</i> root.	<i>Streptomyces aureofaciens</i> CMUAc130 (fungus).	Secondary metabolites were identified as 5,7-dimethoxy-4-p-methoxyphenylcoumarin and 5,7-dimethoxy-4-phenylcoumarin. Antifungal activity through dual cultures assay showed that the fungus inhibit the growth of <i>F. oxysporum</i> and <i>Colletotrichum musae</i> . Both purified compounds inhibit <i>F. oxysporum</i> and <i>C. musae</i> as shown by paper-disc assay.	(Taechowisan et al., 2005)
<i>Z. officinale</i> root	<i>Pseudomonas</i> sp., <i>Ochrobactrum</i> sp., <i>Pseudomonas</i> sp., <i>Serratia</i> sp., <i>Ochrobactrum</i> sp. and <i>Bacillus</i> sp. (bacteria).	The bacteria isolated were tested on <i>Zea mays</i> during field experiment. The results showed that these bacteria have positive effects on overall physiological development and nutrient contents of <i>Z. mays</i> . They can be used as an alternative to chemical fertilizer.	(Zhang et al., 2018)
<i>Z. officinale</i> rhizome	<i>T. harzianum</i> (fungus).	Multiple metabolites have been extracted from the fungal such as pretrichodermamide G, pretrichodermamide A, epicorazine A, and entepicoccin G. Pretrichodermamide A. showed antifungal effects towards <i>Ustilago maydis</i> while antibacterial properties were shown against <i>Mycobacterium tuberculosis</i> . Extracts of epicorazine A contain antifungal activity against <i>U. maydis</i> and showed cytotoxic properties towards the mouse lymphoma cell.	(Harwoko et al., 2021b)
<i>Zingiber zerumbet</i> rhizome	<i>Fusarium solani</i> and <i>Fusarium oxysporum</i> (fungi).	<i>F. solani</i> and <i>F. oxysporum</i> have antagonistic activity against <i>Pythium myriotylum</i> , a major soil-borne phytopathogen. This result determines the capability of <i>Z. zerumbet</i> endophytes as promising resources for active compounds and as biocontrol agents for soft rot disease management caused by <i>Pythium spp.</i>	Keerthi et al. (2016)
<i>Zingiber zerumbet</i> rhizome	<i>F. oxysporum</i> (ZzEF8) fungus	The disc diffusion experiment validated the inhibitory activity of <i>F. oxysporum</i> (ZzEF8) against <i>P. myriotylum</i> .	Keerthi et al. (2022).

CONCLUSION AND FUTURE PERSPECTIVES

Comprehensive research on endophytes in various members of Zingiberaceae proposes that endophytes facilitate improving plant’s productivity as well as protecting plants against multiple stresses. Endophytes and Zingiberaceae plants show a lot of mutualistic symbiosis events such as IAA phytohormone production, siderophore production, modulation of ACC deaminase activity and assist in phosphate solubilization activity in the soil. For biofertilizer, the endophytes isolated from the Zingiberaceae plants have a great potential to be commercialized where it has a progressive impact on the environment with less chemical fertilizer application. Research findings demonstrate that bioinoculation of micropropagated plantlets with endophytes can be used to improve the survival and plants growth during the acclimatization process. Equally important, most endophytes from Zingiberaceae have the promising potential to be sources of secondary metabolites with extensive industrial and medicinal uses. In conclusion, endophytes from Zingiberaceae plants have a lot of benefits with a massive economic opportunity to be developed and commercialized in the future.

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