JOURNAL OF TROPICAL LIFE SCIENCE
2023, Vol. 13, No. 1, 183 – 192
http://dx.doi.org/10.11594/jtls.13.01.18

Review Article

An Overview of Stress-Tolerant Promoting Endophytic Fungal Isolates from Hiyung Chilli Grown in South Kalimantan

Witiyasti Imaningsih [1, 2]*, Nuraeni Ekowati [2], Salamiah [3], Nuniek Ina Ratnaningtyas [2], Loekas Soesanto [4]

[1] Microbiology Laboratory, Biology Study Program, Mathematic and Natural Science Faculty, Universitas Lambung Mangkurat, 70714, Banjarbaru-South Kalimantan, Indonesia
[2] Biology Faculty, Universitas Jenderal Soedirman, 53122, Purwokerto-Central Java, Indonesia
[3] Faculty of Agriculture, Universitas Lambung Mangkurat, 70714, Banjabaru-South Kalimantan, Indonesia
[4] Faculty of Agriculture, Universitas Jenderal Soedirman, 53122, Purwokerto-Central Java, Indonesia

Article history:
Submission July 2022
Revised July 2022
Accepted September 2022

**Corresponding author:*
E-mail: witiyastiimaningsih@ulm.ac.id

ABSTRACT

Endophytic fungi are a unique class of microorganisms that lives in plant tissues. These fungi could spread from roots to shoots and interact with nearly all plants in a symbiotic, mutualistic, or commensal manner. Endophytic fungi are believed to exert several roles related to plant growth, including the ability to tolerate stress, especially in Hiyung chilli plants. This plant is widely cultivated in Indonesia and is a well-known host for endophytic fungi. The Hiyung chilli is a popular variety grown in the South Kalimantan Province, which receives national recognition and is geographically certified by the Indonesian government. This wetland-cultivated chilli plant has a uniquely high capsaicin content and long fruit shelf life compared to other varieties. Although endophytic fungal isolates are prevalently found on chilli plants, their potential to influence the growth of their host remains to be proven beyond a doubt. This review emphasizes the sparse reports on the potential of these antagonistic fungi in protecting chilli plants against other pathogens by producing auxin/Indole-3-Acetic Acid (IAA) and capsaicin. The study hypothesised that the antagonistic abilities of these endophytic fungi against other fungal pathogens are related to their IAA- and capsaicin production that synergistically increase the chili plant's threshold against biotic and abiotic stress.

Keywords: Anti-pathogenic fungi, Auxin, capsaicin, Indonesian chilli, South Kalimantan

Introduction

Hiyung chilli pepper is a protected variety cultivated in the wetlands of Hiyung village, Tapin Regency, in South Kalimantan Province [1–3]. It is worth noting that this chilli plant is a designated national variety by the Ministry of Agriculture of the Republic of Indonesia [4]. Interestingly, the variant also has its own certificate of geographical indication [5]. The advantages of Hiyung chilli pepper are stated in the attachment to the decree of the Minister of Agriculture No. 031 /Kpts /SR.120 /D.2.7 /4 /2016. This high-producing variety produces highly spicy chillies (capsaicin content is more than 2000 ppm) and has a long shelf life of over 6 days [1].

According to the literature, these spicy peppers grow rather well as they act as hosts to endophytic fungi, which are known for their ability to inhibit the growth of the pathogenic fungus, *Colletotrichum capsici* [6, 7]. Endophytic fungi isolated from chilli plants purportedly have a variety of uses, including supporting plant growth [8–15], and are a source of bioactive compounds, for instance, capsaicin [16]. Endophytic fungi isolated from chilli plant reported so far are the *Tricho-*

How to cite:
Imaningsih W, Ekowati N, Salamiah et al. (2023) An Overview of Stress-Tolerant Promoting Endophytic Fungal Isolates from Hiyung Chilli Grown in South Kalimantan. Journal of Tropical Life Science 13 (1): 183 – 192. doi: 10.11594/jtls.13.01.18.

derma sp. [6, 7], *Gliocladium* sp. [7, 17], *Aspergillus* sp. [17, 18], *Curvularia* sp. [19], *Alternaria* sp., *Colletotrichum* sp., and *Cordyseps* sp. [20]. These fungal isolates grow internally in their hosts and are associated with promoting healthy plant tissues. Most importantly, their presence does not interfere with growth [21] or produce unwanted symptoms in the plants [22].

It said that endophytic fungi positively affect the growth of the host plant because of the phytohormones they produce, such as auxins [15, 26]. These fungi also secrete the same bioactive compounds as their host plants [27]. For instance, the antagonistic endophytic fungus, *Alternaria alternata*, isolated from chilli plants, was shown to produce capsaicin, which is the very same compound found in chillies, too [16]. In this perspective, the interesting antagonistic feature of endophytic fungi warrants further research by the scientific community. The focus should be to uncover their role in protecting and promoting the growth of Hiyung chilli plants, consequently, improving their biotic and abiotic stress tolerance [5]. However, it is apparent that exploratory studies correlating the positive effects of endophytic fungi growing on Hiyung chillies remain sparse. This is because the fungal's antagonistic properties through auxin and capsaicin production are poorly understood.

Biology of Hiyung Chilli Endophytic Fungi

The term endophytic fungi were first proposed by Christian et al. [25], defined as fungi that can penetrate plant tissues and undergo several life cycles within them. This fungus lives internally on healthy plant tissues without interfering with the plant's growth [21] and does not produce unwanted symptoms [23]. Most mycologists argue that the composition of endophytes (internal mycobiota) is different for each host, organ, or tissue. Certain endophytic species were discovered as epiphytic or rhizosphere microbiota, though the concept of endophytic fungi was altered as research progressed [24–26].

Endophytic fungi infection on host plants begins with the formation of fungal colonies. The fungus proliferates in tandem with the maturation of the host's root tissues, forming thicker hyphae in differentiated epidermal and cortical cells. An intercellular sub-epidermal hyphae is less likely to colonize the elongation zone since this structure tends to overrun the root cap. After germination, chlamydospores form a network of hyphae in the roots before branching into the host's intercellular space in the sub-epidermal regions. Fungal colonies are formed when single hyphae cells occupy the differentiated young root tissue, where the intercellular hyphae branch and traverse the cell wall [27].

Table 1. Symbiotic Criteria Used For The Characterization Of Classes Of Endophytic Fungi [24].

Criteria	**Clavicipitaceous**	**Nonclavicipitaceous**		
	Class 1	Class 2	Class 3	Class 4
Host range	Narrow	Broad	Broad	Broad
Colonized tissue	Shoots and rhizome	Shoots, roots and rhizoma	Shoot	Root
Colonization on plants	Broad	Broad	Limited	Broad
Biodiversity in plants	Low	Low	High	Unknown
Transmission	Vertical and horizontal	Vertical and horizontal	Horizontal	Horizontal

Endophytic fungi are divided into two major groups based on evolution, taxonomy, host plants, and ecological relationships, namely the clavicipitaceous (C-endophytes) and non-clavipitaceous (NC-endophytes) groups. The clavicipitaceous (C) and nonclavicipitaceous (NC) endophytes are discerned by their phylogeny and evolutionary characteristics. However, the C-endophytes exists symbiotically with grass, while the NC-endophytes are symbiotic with hosts other than grass [24]. The characteristics of the endophytic fungi classes are shown in Table 1.

As can be seen, endophytic fungi isolated from Hiyung chilli belongs to class 2. Members of this class are more diverse and widely distributed in various ecosystems, comprising the phylum Ascomycota and Basidiomycota, capable of growing in various plant tissues, and transmittable vertically and horizontally. As they can transition between endophytic and free-living fungi, their role in the

Table 2. Endophytic fungi of chili plant origin and their potential as anti-pathogenic fungi.

No	Genus	Endophytic Fungi Isolate	Pathogenic fungi	Reference
1.	*Trichoderma*	*Trichoderma* sp.	*Colletotrichum capsici*	[6, 7]
2.	*Gliocladium*	*Gliocladium* sp.	*Colletotrichum capsici*	[7, 17]
3.	*Harmoniella*	*Harmoniella* sp.	*Colletotrichum capsici*	[7]
4.	*Humicola*	*Humicola* sp.	*Colletotrichum capsici*	[7]
5.	*Cunninghamela*	*Cunninghamela* sp.	*Colletotrichum capsici*	[7]
6.	*Aspergillus*	*Aspergillus flavus, Aspergillus niger*	*Colletotrichum capsici*	[17, 20]
7.	*Colletotrichum*	*Colletotrichum acutatum*	*Fusarium oxysporum*	[20]
		Cladosporium gossypiicola, Cladosporium colombia	*Colletotrichum acutatum; Fusarium oxysporum; Phytophthora capsici*	
8.	*Cordyceps*	*Cordyceps nutans*	*Colletotrichum acutatum; Fusarium oxysporum;*	[20]
9.	*Penicillium,*	*Penicillium oxalicum, Penicillium citrinum, Penicillium gossypiicola, Penicillium crustosum, Penicillium expansum*	*Colletotrichum acutatum/Fusarium oxysporum/Phytophthora capsici*	[17, 20]
10.	*Xylaria*	*Xylaria* sp.	*Colletotrichum acutatum* and *Fusarium oxysporum*	[20]
11.	*Rhizoctonia*	*Rhizoctonia* sp.	*Colletotrichum capsici*	[17]
12.	*Hormiscium*	*Hormiscium* sp.	*Colletotrichum capsici*	[17]

environment, evolutionarily, physiologically and ecologically, must be viewed with caution [24].

Biodiversity and Potential of Chilli Plant Endophytic Fungi

Table 2 enlists the known symbiotic relationship between several types of endophytic fungi with different varieties of chilli plants. The endophytic fungal species isolated from chilli plants include *Trichoderma* sp. [6], *Botrytis* sp., *Gliocladium* sp., *Harmoniella* sp., *Humicola* sp., *Cunninghamela* sp. [7], *Aspergillus flavus*, *Nigrospora* sp., *Coniothyrium* sp. [18], *Cercospora nicotianae*, *Curvularia* sp., and *Fusarium* sp. [19]. There are several fungal genera isolated from chilli plants of Korean origin, namely *Alternaria, Aspergillus, Bionectria, Chaetomium, Cladosporium, Colletotrichum, Cordyceps, Fusarium, Geomyces, Gnomonia, Heterobadisidion, Irpex, Paecilomyces, Paparspora, Penicillium, Peyronellaea, Phanerochaete, Phialophora, Phlebiospsis, Plectosphaerella* and *Xylaria* [20]. Other species also reported include *Rhizoctonia* sp., *Aspergillus niger*, and *Hormiscium* sp. [17]. Most of these endophytic fungi are isolated from root tissue, stems, and leaves [20].

Specifically, the endophytic fungi can intracellularly and intercellularly enter plant tissues in the rhizosphere and phyllosphere regions through wound openings in roots or stomata on the leaves [21, 23]. Their growth in plant tissue thus affects the anatomical structure [24, 25] and growth of the host plant [26].

The Role of Endophytic Fungi in Sustainable Hiyung Chilli Farming in Swamplands

Swamp land is naturally inundated, either periodically or continuously, due to obstructed drainage caused by tide, river overflow, and rain [32, 4]. Chilli farming in Hiyung village is done in lowland swamp lands [4]; in which the soil is very acidic (pH 3.84). The soil also has high organic carbon content and moderate sodium, phosphate, and potassium levels [4]. However, the everchanging environmental conditions in Hiyung village can unfavorably impact plant development and growth [33]; thus, forcing the plants to adapt to their surroundings. Abiotic stress in plants may

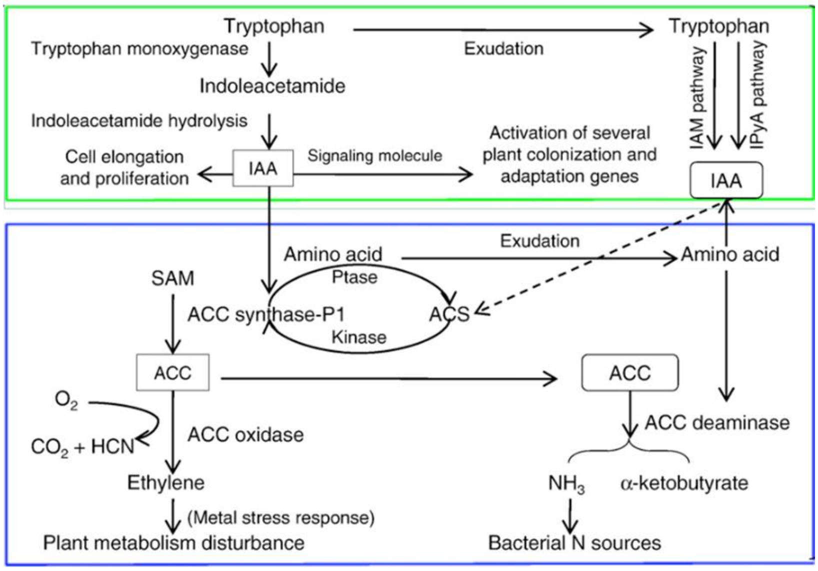

Figure 1. The mechanism of endophytic microbial growth hormones in supporting plant growth. Image adapted from Bae et al. [39].

include water content, acidity, and soil organic matter content. And biotic stress such as pathogen attack. Plants employ a variety of stress-tolerant mechanisms comprising physiological or molecular ones to adapt to environmental changes [4] successfully. These changes are often assisted by microorganisms, such as endophytic fungi [33].

Environmentally friendly and safe farming approaches are the focus of current research as the demand for agricultural products increases. Various strategies are implemented to support sustainable agriculture and increase crop production while minimizing environmental damage and improving human welfare. As a matter of fact, the symbiotic nature of endophytic fungi-plants is an alternative in sustainable agriculture because of their potential for increasing plant tolerance to biotic and abiotic stress, in addition to improving growth [34]. Several studies reported the crucial role of endophytic microbes in supporting plant growth. They found that these endophytic microbes were lost during domestication and the long-term cultivation of certain crops. However, the issue was solvable by transferring endophytes from related wild plants to cultivated ones [34]. Hence, it can be construed that sustainable agriculture is not possible without these antagonistic endophytic fungi.

Another vital contribution of endophytic fungi is their ability to affect their host plants to adapt to varying abiotic and biotic stress. Certain fungi improve plant fitness by producing certain chemicals that enhance the host's tolerance to biotic and abiotic stress, for instance, inhibiting pathogens and producing phytohormones [24].

Potential of Endophytic Fungi as Anti-Pathogenic Fungi

Literature has shown that the mechanism of pathogen inhibition by endophytic fungi can indirectly support plant growth and inhibit the growth of pathogenic fungi through antibiosis, competition, or mycoparasitism. These mechanisms were observed in endophytic fungi from Galam (*Melaleuca cajuputi*) [35] and rice (*Oryza sativa* L.) [36]. A *Trichoderma* sp. isolate employed the above-said mechanisms to inhibit the growth of pathogenic *P. capsici* [37] and *Colletotrichum* sp. [6]. Table 2 denotes various endophytic fungi isolated from the chilli plant, which exhibited inhibitory ability against several pathogenic fungi (Table 2.) [17, 20, 38]. The fungal species isolated from the roots of Hiyung chilli plants, including *Harmoniella* sp., *Cunninghamela* sp., *Humicola* sp., were effective in inhibiting *C. capsici* [7].

The Potential of Endophytic Fungi in Helping Plant Growth through the Production of Indole-3-Acetic-Acid (IAA)

It is worth noting that endophytic fungi also produce phytohormones, which elevates the plant host's ability to tolerate environmental stresses [29, 38, 39] (Figure 1). Phytohormones isolated from these microorganisms include auxins (IAA), cytokinins, and gibberellin. The hormones support

Figure 2. Hiyung chili farm (a, b), chilli fruits (c) and chilli-bearing mature plants (d).

germination, growth, and reproduction and protect plants from biotic and abiotic stress [41]. In fact, IAA is one of the most studied phytohormones produced by endophytic fungi [15, 39], which include cell elongation and division, and is a part of the plants' defence system. It was documented that different IAA biosynthetic pathways regulate different types of plant-microbial interactions [42].

A mutualistic symbiotic microorganism-plant interaction is linked to the synthesis of IAA through the indole-3-pyruvate (IPyA) pathway. Conversely, pathogens mainly use the indole-3-acetamide pathway or (IAM). Also, the amount of IAA liberated by plants affects the efficacy of plant-microbial interactions. Literature has shown that at high IAA concentrations, root elongation is inhibited, and this outcome is related to 1-aminocyclopropane-1-carboxylic acid (ACC) synthesis. Through ethylene synthesis, plant growth is regulated by direct or indirect hormonal balance [43–45].

Another reported interesting observation is that plants inoculated with endophytic fungi grow better than uninoculated ones [8, 10, 15, 42, 43]. This is because the introduced endophytic fungi act as growth-promoting agents through the production of IAA [11, 15, 47] and auxin. In particular, the latter promotes cell differentiation and elongation in host plant tissues and subsequently improves the number of lateral roots and shoot length [44].

Endophytic Fungi from Hiyung Chilli as a Source of Capsaicin

Certain endophytic fungi produce metabolites similar to their hosts. The compounds comprise alkaloids, terpenoids, quinones, steroids, phenols, shikimates, xanthones, and isoprenoids [21]. These compounds are known for their anti-inflammatory and anti-cancer properties [45]. Interestingly, endophytic fungi isolated from *Capsicum annuum* were also found to produce capsaicin [16]. For brevity, capsaicin (trans-8-methyl-N-vanillyl-6-nonenamide) is an alkaloid of the capsaicinoid group in the vanilloid family, following the presence of a vanillyl group in its structure. The compound also has a benzene ring endowed with a long hydrophobic carbon chain and a polar amide group. The lowly volatile capsaicin is aromatic solvent-soluble but is insoluble in water [46].

There are consistent reports on the role of capsaicin as a defence mechanism in chilli plants against pathogens [48]. Another fascinating observation on the use of this compound, is that the external application of capsaicin to chilli seeds inhibited seed germination. On that premise, capsaicin from chili peppers might also be valuable in inhibiting weed, i.e., a herbicide [52]. Additionally, the compound enhances the resistance of chilli plants to fungal and bacterial pathogens and insects [51, 52]. The higher concentration of capsaicin in chilli plants grown in humid environments was also found to reduce the plants' susceptibility to pathogenic fungal infections. Contrariwise, studies showed that chilli plants grown in arid conditions have lower spiciness levels due to lower capsaicin content. The reduced capsaicin content in these chili plants was due to lower incidences of pathogenic fungal attacks on plants in dry conditions, which do not support their growth. In the case of Hiyung chilli plants, their observably higher capsaicin content is likely an evolutionary adaptation of the plant's defence mechanisms for growth in wetlands.

However, certain pathogenic fungi have developed novel mechanisms to nullify the effects of surplus capsaicin secreted by chilli plants. These counter-mechanisms include the production of multiple enzymes that specifically degrade capsaicin [56], which renders the surplus capsaicin useless in protecting the chili plants.

Hiyung Chilli Local Variety of South Kalimantan, Advantages and Potential of Endophytic Fungi

As the name implies, the chilli comes from the Hiyung village of the Tapin Regency in South Kalimantan (Figures 2(a) and (b)). Morphologically, it has a greenish-purple fruit when young, which gradually turns bright red when matured. The mature fruit is an elongated tapered shape (Figure 2c), and the plant is a shrub with tapered leaves [3]. The similarity coefficient between the Hiyung chilli variety with Nirmala was the highest after morphological observations on 14 chilli varieties [57]. The Nirmala variety is a hybrid cayenne pepper that is relatively resistant to *Ralstonia solanacearum* [58].

Other traits of the Hiyung chilli are its high fruit yield per plant, its extreme spiciness reaching up to 2333.05 ppm, and its high vitamin C content of 66.85 mg / l00 g [3, 5]. However, the spiciness level reduces when it is grown elsewhere. The fruit also has a long shelf life and could be stored for long durations, up to 10-16 days, at room temperature [3-5].

Based on the literature, IAA phytohormones secreted by endophytic fungi through ethylene metabolism [39], are also produced by plants under duress [60]. For instance, the *Cuninghamella* sp. endophytic fungi produce phytohormones, including IAA, that affect germination [7]. The unusually high capsaicin content in Hiyung chilli compared to other varieties from Mexico, Saudi Arabia, and the USA, also points to its potential for other applications, for example, as an ingredient in pharmaceutical preparations (Table 3). However, the capsaicin content in Hiyung chilli is lower than the Bhut Jolokia variety from Russia.

The high capsaicin content in Hiyung chilli also conveys essential information on the possible metabolites produced by the plant's endophytic symbionts. This is consistent with several reports on these fungi producing metabolites similar to their symbionts [60]. However, further investigations are needed to clarify the facts regarding the association between the fungi's ability to produce capsaicin and their antagonistic behaviour. Also, earlier research discovered that the dry weight of the Hiyung chilli implies that the variant is suitable for cultivation in swamplands. Furthermore, the highly acidic wetlands can inhibit plant growth [62]. That said, this variety of chilli plants' tolerance of acidic environments warrants further examination to prove their synergistic existence with the endophytic fungi they harbour [63, 64].

Based on the literature, the unique stress-tolerant Hiyung chilli plant was likely linked to its role as a host for endophytic fungi, which invariably inhibited colonisation of other pathogenic fungi. The symbiont also produces IAA and auxin, which

Table 3. *Capsaicin* content of some varieties of hot peppers.

No	Variety name	As long as	Capsaicin (ppm) content	Source
1	Bhut Jolokia	Russia	3.041 - 25.944	[61]
2	Cipanas	Indonesian	9,23	[62]
3	Lembang-1	Indonesian	7,79	[62]
4	Branang	Indonesian	7,44	[62]
5	Gold	Indonesian	4,3	[62]
6	Gantari	Indonesian	7,12	[62]
7	Hiyung	Indonesian	2.333,05	[5]
8	Red-pepper	USA	228	[63]

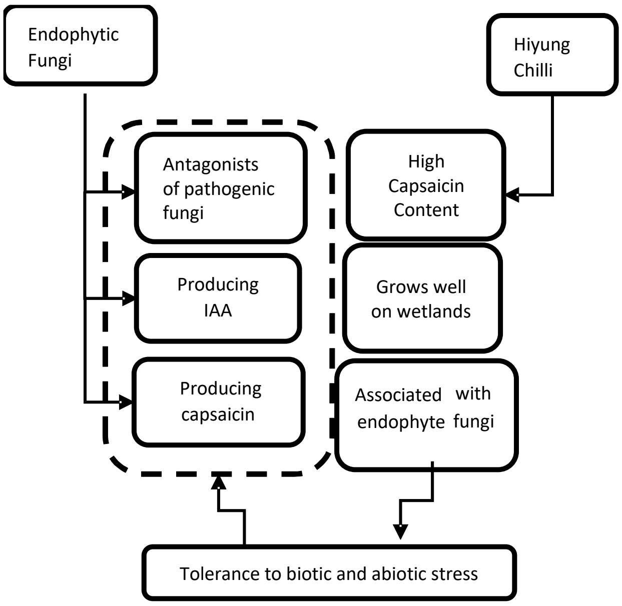

Figure 3. A schematic showing the mechanism by endophytic fungi to enhance biotic and abiotic stress tolerance in their host plants.

protect the plant host. However, further efforts are needed to prove this hypothesis pertaining to the Hiyung chilli endophytic fungal isolates. Figure 3 illustrates the mechanisms adopted by endophytic fungi to enhance biotic and abiotic stress tolerance in their host plants.

Conclusion

As can be seen, the superior quality of Hiyung chilli is seen to be synonymous with their existence as a symbiont of certain endophytic fungi. So far, their function as antifungal agents and their ability to produce auxin and capsaicin are hypothesised to contribute to the higher stress tolerance in Hiyung chilli plants over other varieties. Nevertheless, future exploratory studies are needed to fully comprehend the above-said mechanisms induced by these endophytic fungal isolates on their Hiyung chilli symbiont, which produces more robust plants.

Acknowledgment

We would like to convey our deepest gratitude to Mr. Junaidi, the head of the Karya Baru farmer group of Hiyung Village, for his commitment and assistance throughout this study.

References

1. Hamdani, Salawati U, Nuryadin R (2017) Daya Saing Agribisnis Dan Potensi Pengembangan Cabe Hiyung Di Kabupaten Tapin, Kalimantan Selatan. Prosiding Seminar Nasional Lahan Basah Jilid 1 156–163.
2. Sutomo, Rahmawati A, Rizki MI (2017) Standarisasi Buah Cabe Rawit Hiyung (*Capsicum frutescen*s L .) Asal Tapin Kalimantan Selatan. 2 (September): 245–253. doi: 10.36387/jiis.v2i2.121.
3. Wahdah R, Rahmawati Y, Nafarin Y et al. (2016) Deskripsi Cabai Rawit Varietas Hiyung. Lampiran Surat Keputusan Menteri Pertanian Republik Indonesia Nomor : 031/Kpts/SR.120/D.2.7/4/2016 Deskripsi.
4. Pramudyani L, Sabran M, Noor A (2019) Agronomic Performance and Nutrition Content of Hiyung as Local Variety of Cayenne Pepper [*Capsicum frutescens*] at Dry Land and Swamp Land of South Kalimantan Province. Buletin Plasma Nutfah 25 (1): 43. doi: 10.21082/blpn.v25n1.2019.p43-52.
5. Direktorat Merek dan Indikasi Geografis KEMENKUMHAM (2019) Berita Resmi Indikasi Geografis Seri-A no.No. 17/IG/X/A/2019. Direktorat Merek dan Indikasi Geografis. Direktorat Jenderal Kekayaan Intelektual. KEMENKUMHAMRI.
6. Budi IS, Mariana M (2016) Controlling Anthracnose Disease of Locally Chili in Marginal Wetland using Endophytic Indigenous Microbes and Kalakai (*Stenochlaena palustris*) Leaf Extract. Journal of Wetlands Environmental Management 4 (1): 28–34. doi: 10.20527/jwem.v4i1.51.
7. Imaningsih W, Mariana, Junaedi AB, Rasyidah (2021) Antifungal activities of the combination of ulin wood liquid smoke and hiyung cayenne pepper root endophyte fungi against *Colletothricum capsici*. Agrivita 43 (1): 69–78. doi: 10.17503/agrivita.v1i1.2458.
8. Herrera-Parra E, Cristóbal-Alejo J, Ramos-Zapata JA (2017) *Trichoderma* strains as growth promoters in *Capsicum annuum* and as biocontrol agents in *Meloidogyne incognita*. Chilean Journal of Agricultural Research 77 (4): 318–324. doi: 10.4067/S0718-58392017000400318.
9. Handayani D, Fifendy M, Yesni V (2018) Isolation of Phosphate Solubilizing Endophytic Fungi From Rice

Plant Root. Bioscience 2 (1): 93. doi: 10.24036/020182110043-0-00.
10. Sati SC, Pant P (2019) Two Root Endophytic Aquatic Hyphomycetes *Campylospora parvula* and *Tetracladium setigerum* as Plant Growth Promoters. Asian Journal of Agricultural Research 14 (1): 28–33. doi: 10.3923/ajar.2020.28.33.
11. Khan MS, Gao J, Munir I et al. (2021) Characterization of Endophytic Fungi, *Acremonium* sp., from *Lilium davidii* and Analysis of Its Antifungal and Plant Growth-Promoting Effects. BioMed Research International 2021 1–14. doi: 10.1155/2021/9930210.
12. Singh N, Singh A, Dahiya P (2021) Plant Growth-Promoting Endophytic Fungi from Different Habitats and Their Potential Applications in Agriculture. pp 69–87.
13. Rigobelo EC, Baron NC (2021) Endophytic fungi: a tool for plant growth promotion and sustainable agriculture. Mycology 13 (1): 39-55. doi: 10.1080/21501203.2021.1945699.
14. Syamsia S, Idhan A, Firmansyah AP et al. (2021) Combination on endophytic fungal as the Plant Growth-Promoting Fungi (PGPF) on cucumber (*Cucumis sativus*). Biodiversitas Journal of Biological Diversity 22 (3): 1194–1202. doi: 10.13057/biodiv/d220315.
15. Imaningsih W, Rahayu ND, Hakim SS (2021) Endophytes and Rhizosphere Fungi from Galam (*Melaleuca cajuputi* Powell.) which has the Potential to Produce Indole Acetic Acid (IAA). Journal of Tropical Biodiversity and Biotechnology 6 (2): 61594. doi: 10.22146/jtbb.61594.
16. Devari S, Jaglan S, Kumar M et al. (2014) Capsaicin production by *Alternaria alternata*, an endophytic fungus from *Capsicum annum*; LC-ESI-MS/MS analysis. Phytochemistry 98: 183–189. doi: 10.1016/j.phytochem.2013.12.001.
17. Hutauruk ICP, Hasanuddin, Pinem MI (2020) Ability test of endophytic fungi to suppress the development of anthracnose disease (*Colletotrichum capsici*) in chili plants (*Capsicum annum*) in the Karo Highland. IOP Conf Ser Earth Environ Sci. doi: 10.1088/1755-1315/454/1/012185.
18. Hernawati H, Wiyono S, Santoso S (2011) Leaf endophytic fungi of chili (*Capsicum annuum*) and their role in the protection against *Aphis gossypii* (Homoptera: Aphididae). Biodiversitas Journal of Biological Diversity 12 (4): 187–191. doi: 10.13057/biodiv/d120401.
19. Lestari SM, Hidayat SH, Widodo W (2018) Determination of Endophytic Fungi as Induce Resistance Agent of Chilli Pepper Against Pepper Yellow Leaf Curl Disease. AGRIVITA Journal of Agricultural Science 40 (2): 249–256. doi: 10.17503/agrivita.v40i2.989.
20. Paul NC, Deng JX, Sang H-K et al. (2012) Distribution and Antifungal Activity of Endophytic Fungi in Different Growth Stages of Chili Pepper (*Capsicum annuum* L.) in Korea. The Plant Pathology Journal 28 (1): 10–19. doi: 10.5423/PPJ.OA.07.2011.0126.
21. Rajamanikyam M, Vadlapudi V, Amanchy R, Upadhyayula SM (2017) Endophytic Fungi as Novel Resources of natural Therapeutics. Arch Biol Technol v Arch Biol Technol v 606060 (December): 1–26. doi: 10.1590/1678-4324-2017160542.
22. Abhijeet Singh YM (2014) Understanding the Biodiversity and Biological Applications of Endophytic Fungi: A Review. J Microb Biochem Technol. doi: 10.4172/1948-5948.S8-004.
23. Abhijeet Singh YM (2014) Understanding the Biodiversity and Biological Applications of Endophytic Fungi: A Review. J Microb Biochem Technol. doi: 10.4172/1948-5948.s8-004
24. Rodriguez RJ, White JF, Arnold AE, Redman RS (2009) Fungal endophytes: Diversity and functional roles: Tansley review. New Phytologist 182 (2): 314–330. doi: 10.1111/j.1469-8137.2009.02773.x.
25. Christian N, Herre EA, Clay K (2019) Foliar endophytic fungi alter patterns of nitrogen uptake and distribution in *Theobroma cacao*. New Phytologist 222 (3): 1573–1583. doi: 10.1111/nph.15693.
26. Nair DN, Padmavathy S (2014) Impact of endophytic microorganisms on plants, environment and humans. Sci World J. doi: 10.1155/2014/250693
27. Deshmukh S, Hückelhoven R, Schäfer P et al. (2006) The root endophytic fungus *Piriformospora indica* requires host cell death for proliferation during mutualistic symbiosis with barley. Proceedings of the National Academy of Sciences 103 (49): 18450–18457. doi: 10.1073/pnas.0605697103.
28. Lata R, Chowdhury S, Gond SK, White JF (2018) Induction of abiotic stress tolerance in plants by endophytic microbes. Letters in Applied Microbiology 66 (4): 268–276. doi: 10.1111/lam.12855.
29. Hiruma K, Gerlach N, Sacristán S et al. (2016) Root Endophyte *Colletotrichum tofieldiae* Confers Plant Fitness Benefits that Are Phosphate Status Dependent. Cell 165 (2): 464–474. doi: 10.1016/j.cell.2016.02.028.
30. Paradiso R, Arena C, De Micco V et al. (2017) Changes in leaf anatomical traits enhanced photosynthetic activity of soybean grown in hydroponics with plant growth-promoting microorganisms. Frontiers in Plant Science 8 (May): 1–13. doi: 10.3389/fpls.2017.00674.
31. Suebrasri T, Harada H, Jogloy S et al. (2020) Auxin-producing fungal endophytes promote growth of sunchoke. Rhizosphere 16 (100271): 100271. doi: 10.1016/j.rhisph.2020.100271.
32. Hayati A, Hardarani N (2019) Karakteristik Lahan dan Budidaya Cabai Rawit Hiyung: Informasi Dasar untuk Peningkatan Produksi Cabai Rawit Hiyung di Lahan Rawa Lebak. Prosding Seminar Nasional Lingkungan Lahan Basah 4 (1): 57–59.
33. Mathivanan S (2021) Abiotic Stress-Induced Molecular and Physiological Changes and Adaptive Mechanisms in Plants. In: Abiotic Stress Plants. IntechOpen, pp 137–144.
34. Manganyi MC, Ateba CN (2020) Untapped potentials of endophytic fungi: A review of novel bioactive compounds with biological applications. Microorganisms 8 (12): 1–25. doi: 10.3390/microorganisms8121934.
35. Huda N, Imaningsih W, Hakim SS (2019) Uji Antagonisme Kapang Endofit Tanaman Galam (*Melaleuca cajuputi*) terhadap *Colletotrichum truncatum*. Jurnal Mikologi Indonesia 3 (2): 59. doi: 10.46638/jmi.v3i2.62.
36. Imaningsih W, Adventaria D, Mariana, Junaidi AB (2022) Inhibitory Effect Of Ulinwood Liquid Smoke and Gogo Rice Endophytic Fungi Against Pathogen *Pyricularia oryzae*. Biotropia 29 (1): 23–32. doi: 10.11598/btb.2022.29.1.1568.
37. Bae H, Roberts DP, Lim H-S et al. (2011) Endophytic *Trichoderma* Isolates from Tropical Environments Delay

Disease Onset and Induce Resistance Against *Phytophthora capsici* in Hot Pepper Using Multiple Mechanisms. Molecular Plant-Microbe Interactions® 24 (3): 336–351. doi: 10.1094/MPMI-09-10-0221.
38. Nurzannah S, Lisnawita L, Bakti D (2014) Potensi Jamur Endofit Asal Cabai Sebagai Agens Hayati Untuk Mengendalikan Layu Fusarium (*Fusarium Oxysporum*) Pada Cabai Dan Interaksinya. Jurnal Agroekoteknologi Universitas Sumatera Utara 2 (3): 100407. doi: 10.32734/jaet.v2i3.7543.
39. Lubna, Asaf S, Hamayun M et al. (2018) *Aspergillus Niger* CSR3 regulates plant endogenous hormones and secondary metabolites by producing gibberellins and indoleacetic acid. Journal of Plant Interactions 13 (1): 100–111. doi: 10.1080/17429145.2018.1436199.
40. Herrera-Parra E, Cristóbal-Alejo J, Ramos-Zapata JA Trichoderma strains as growth promoters in Capsicum annuum and as biocontrol agents in Meloidogyne incognita. Chil J Agric Res. doi: 10.4067/S0718-58392017000400318.
41. Egamberdieva D, Wirth SJ, Alqarawi AA et al. (2017) Phytohormones and Beneficial Microbes: Essential Components for Plants to Balance Stress and Fitness. Frontiers in Microbiology 8 (OCT): 1–14. doi: 10.3389/fmicb.2017.02104.
42. Zhao Y (2010) Auxin biosynthesis and its role in plant development. Annual Review of Plant Biology 61 (May): 49–64. doi: 10.1146/annurev-arplant-042809-112308.
43. Ma Y, Prasad MNV, Rajkumar M, Freitas H (2011) Plant growth promoting rhizobacteria and endophytes accelerate phytoremediation of metalliferous soils. Biotechnology Advances 29 (2): 248–258. doi: 10.1016/j.biotechadv.2010.12.001.
44. Glick BR, Todorovic B, Czarny J et al. (2007) Promotion of Plant Growth by Bacterial ACC Deaminase. Critical Reviews in Plant Sciences 26 (5–6): 227–242. doi: 10.1080/07352680701572966.
45. Persello-Cartieaux F, Nussaume L, Robaglia C (2003) Tales from the underground: Molecular plant-rhizobacteria interactions. Plant, Cell and Environment 26 (2): 189–199. doi: 10.1046/j.1365-3040.2003.00956.x.
46. Noriler SA, Savi DC, Aluizio R et al. (2018) Bioprospecting and Structure of Fungal Endophyte Communities Found in the Brazilian Biomes, Pantanal, and Cerrado. Frontiers in Microbiology 9 (JUL): 1–14. doi: 10.3389/fmicb.2018.01526.
47. Turbat A, Rakk D, Vigneshwari A et al. (2020) Characterization of the Plant Growth-Promoting Activities of Endophytic Fungi Isolated from Sophora flavescens. Microorganisms 8 (5): 683. doi: 10.3390/microorganisms8050683.
48. Alarcón MV, Salguero J, Lloret PG (2019) Auxin modulated initiation of lateral roots is linked to pericycle cell length in Maize. Frontiers in Plant Science 10 (January): 1–10. doi: 10.3389/fpls.2019.00011.
49. Singh A, Singh DK, Kharwar RN et al. (2021) Fungal Endophytes as Efficient Sources of Plant-Derived Bioactive Compounds and Their Prospective Applications in Natural Product Drug Discovery: Insights, Avenues, and Challenges. Microorganisms 9 (1): 197. doi: 10.3390/microorganisms9010197.
50. Al Othman ZA, Ahmed YBH, Habila MA, Ghafar AA (2011) Determination of capsaicin and dihydrocapsaicin in *Capsicum* fruit samples using high performance liquid chromatography. Molecules 16 (10): 8919–8929. doi: 10.3390/molecules16108919.
51. Tewksbury JJ, Reagan KM, Machnicki NJ et al. (2008) Evolutionary ecology of pungency in wild chilies. Proceedings of the National Academy of Sciences of the United States of America 105 (33): 11808–11811. doi: 10.1073/pnas.0802691105.
52. Barchenger DW, Bosland PW (2016) Exogenous applications of capsaicin inhibits seed germination of *Capsicum annuum*. Scientia Horticulturae 203: 29–31. doi: 10.1016/j.scienta.2016.03.009.
53. Luna-ruiz JDJ, Nabhan GP, Aguilar-meléndez A (2018) Shifts in Plant Chemical Defenses of Chile Pepper (*Capsicum annuum* L.) Due to Domestication in Mesoamerica. doi: 10.3389/fevo.2018.00048
54. Chabaane Y, Marques Arce C, Glauser G, Benrey B (2022) Altered capsaicin levels in domesticated chili pepper varieties affect the interaction between a generalist herbivore and its ectoparasitoid. Journal of Pest Science 95 (2): 735–747. doi: 10.1007/s10340-021-01399-8.
55. Haak DC, McGinnis LA, Levey DJ, Tewksbury JJ (2012) Why are not all chilies hot? A trade-off limits pungency. Proceedings of the Royal Society B: Biological Sciences 279 (1735): 2012–2017. doi: 10.1098/rspb.2011.2091.
56. Adams CA, Zimmerman K, Fenstermacher K et al. (2020) Fungal seed pathogens of wild chili peppers possess multiple mechanisms to tolerate capsaicinoids. Appl Environ Microbiol. doi: 10.1128/AEM.01697-19
57. Mahmudah N, Badruzsaufari B (2020) Analisis Kekerabatan Fenetik Cabai Hiyung Dengan Beberapa Kultivar Cabai Rawit. Ziraa'ah Majalah Ilmiah Pertanian 45 (2): 135. doi: 10.31602/zmip.v45i2.2997.
58. Menteri Pertanian Republik Indonesia (2011) Deskripsi Cabai rawit Varietas Nirmala.
59. Dey P, Datta D, Saha D et al. (2019) Plant-Endophyte Interaction and Its Application to Abiotic Stress Management of Crop Plants. International Journal of Current Microbiology and Applied Sciences 8 (07): 2708–2716. doi: 10.20546/ijcmas.2019.807.332.
60. Ali S, Charles TC, Glick BR (2017) Functional Importance of the Plant Microbiome. Funct Importance Plant Microbiome Implic Agric For Bioenergy. doi: 10.1007/978-3-319-65897-1.
61. Kumara PM, Shweta S, M, M V et al. (2014) Advances in Endophytic Research, Advances i. Adv Endophytic Res. doi: 10.1007/978-81-322-1575-2
62. Bian M, Zhou M, Sun D, Li C (2013) Molecular approaches unravel the mechanism of acid soil tolerance in plants. Crop Journal 1 (2): 91–104. doi: 10.1016/j.cj.2013.08.002.
63. Mengistu AA (2020) Endophytes: Colonization, Behaviour, and Their Role in Defense Mechanism. International Journal of Microbiology 2020 1–8. doi: 10.1155/2020/6927219.
64. Chitarra W, Hamayun M, Khan AW et al. (2021) Fungal Endophyte: An Interactive Endosymbiont With the Capability of Modulating Host Physiology in Myriad Ways. Front Plant Sci 12: 701800. doi: 10.3389/fpls.2021.701800.
65. Popelka P, Jevinová P, Šmejkal K, Roba P (2017) Determination of Capsaicin Content and Pungency Level of Different Fresh and Dried Chilli Peppers. Folia

Veterinaria 61 (2): 11–16. doi: 10.1515/fv-2017-0012.

66. Orellana-Escobedo L, Garcia-Amezquita LE, Olivas GI et al. (2013) Capsaicinoids content and proximate composition of Mexican chili peppers (*Capsicum* spp.) cultivated in the State of Chihuahua. CyTA - Journal of Food 11 (2): 179–184. doi: 10.1080/19476337.2012.716082.
67. Waite MS, Aubin AJ, Corporation W (2008) A Modular HPLC System for routine Analysis of Capsaicin from Hot Sauces. Waters Corporation 1 (1): 1–5.