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RESEARCH PAPER

Evaluating the Efficacy of Agro-residue Based Culture Media for Growth and Metabolite Production by Endophytic *Fusarium oxysporum, ZzEF*8

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ABSTRACT

Growth media are known to significantly influence secondary metabolite (SM) production with there being a continuing search for cheaper alternatives. Agro-residues constitute potential nutrient sources for growth and metabolite production by different microorganisms. Present study evaluated the potential of rice bran, wheat bran, soyabean chunks and potato peel for umbelliferone (UMB) production by endophytic fungal isolate *ZzEF*8 (*Fusarium oxysporum)* and compared the data with earlier optimized potato dextrose broth (PDB) medium. Biochemical studies identified higher reducing sugar (975±15 mg/ 100 ml) and total carbohydrate content (870±1.3 mg/ 100 ml) in PDB compared to the evaluated agro-residues. These results were supported by higher growth (Fresh weight: 2.08 ± 0.49 g and Dry weight: 0.214 ± 0.06 g) and metabolite production by *ZzEF*8 mycelia in PDB compared to the other evaluated agro-residue based media. Therefore, despite the environmental benefits associated with use of agro-residues, cost-intensiveness in downstream steps and low SM productivity often pose limitations to their utilization for several microbes. PDB as optimal media for growth and UMB production by endophytic *ZzEF*8 are discussed in the light of observed variability in composition of agro-residues.

HIGHLIGHTS

- Agro-residues showed low and variable umbelliferone (UMB) production by endophytic *Fusarium oxysporum*, *ZzEF*8 despite being sustainable alternatives.
- Maximum growth and UMB production by *ZzEF*8 were achieved in potato dextrose broth (PDB) due to its high nutrient content.
- Low nutrient content and variability in agro-residue media limit their effectiveness for metabolite production.

Keywords: Agro-residues, *Fusarium oxysporum*, Secondary metabolite production, Endophyte

Endophyte bioprospecting studies have placed incredible attention on endophytic fungi (EF) due to their diversity and exceptional ability to produce structurally novel and complex secondary metabolites (SMs) (Strobel, G. 2018). Endophytes constitute novel sources of cytotoxic metabolites (Uzma, F. *et al.* 2018), antibacterial molecules (Radic, N. and Strukelj, B. 2012), biostimulants (Poveda, J. *et al.* 2021) and biological control agents (BCAs) (Poveda, J. and Baptista, P. 2020) facilitating nutrient solubilization (Strobel, G. 2018), plant growth promotion (Poveda, J. *et al.* 2021) and induction of plant systemic resistance to biotic (Poveda, J. and Baptista, P. 2020) or abiotic (Cui, R. *et al.* 2021) stress. Studies have reported endophytes to establish either commensalistic or latent pathogenic relationship with the host (Hiruma, K. *et al.* 2016; Alam, B. *et al.*

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2021) or associate as EF which typically include the majority of *Fusarium* spp, that endemically establish in host tissues without causing disease symptoms (Kumar, K.K. and Dara, S.K. 2021). Due to their ability to colonize diverse hosts (Imazaki, I. and Kadota, I. 2015) together with their outstanding biosynthetic ability (Summerell, B.A. and Leslie, J.F. 2011; Bills, G.F. and Gloer, J.B. 2016; Kaul, S. *et al.* 2016), endophytic *Fusarium* spp. have been isolated from diverse plant taxa (Qin, S. *et al.* 2011; Strobel, G. and Daisy, B. 2003). Though *Fusarium* spp. is generally considered as plant pathogens (Michielse, C.B. and Rep, M. 2009; Fisher, M.C. *et al.* 2012; García-Bastidas, F. *et al.* 2014), several studies have shown the symbiotic association of *Fusarium* spp. with host plants (Jumpponen, A. and Jones, K.L. 2009). Studies have identified *Fusarium* spp. to dominate below ground tissues (Guevara-Araya, M.J. *et al.* 2020). Amongst the diverse *Fusarium* species complexes identified till date from belowground tissues of different plants, *Fusarium oxysporum* (*Fo*) has been identified as the most abundant EF (Bao, J. *et al.* 2004) such as in *Aristolochia chilensis* (Guevara-Araya, M.J. *et al.* 2020), lawn grass (*Axonopus compressus*) (Zakaria, L. and Ning, C.H. 2013), *Zingiber zerumbet* rhizome (Keerthi, D. *et al.* 2016), tomato (Bao, J. *et al.* 2004), *Oryza granulata* (Naik, B.S. *et al.* 2009), *Oryza sativa* (Yuan, Z.L. *et al.* 2010) and mangroves (Xing, X. and Guo, S. 2011). Being adapted to diverse geographical sites and climatic conditions, *Fusarium* represents a polyphyletic genus documented with global distribution (Stępień, Ł. *et al.* 2018; Qu, B. *et al.* 2008). Due to their ability to produce biomass degrading hydrolases (da Rosa-Garzon, N.G. *et al.* 2019), *Fusarium* spp can colonize diverse plant hosts as endophytes (Bills, G.F. and Gloer, J.B. 2016; Stępień, Ł. *et al.* 2018). Endophytic *Fusarium* spp. from diverse plant sources have been identified to produce more than 100 SMs (Kaul, S. *et al.* 2016) belonging to structural groups like alkaloids, terpenoids, cytochalasins, steroids, anthraquinone derivatives and phenylpropanoids (Ahmed, A.M. *et al.* 2023). With more than 70 species identified so far, *Fusarium* thus represents a cosmopolitan genus and identified as promising resource for bioactive compounds (Toghueo, R.M.K. 2019). Our earlier studies bioprospecting endophytes from rhizomes of medicinal plant, *Zingiber zerumbet* had isolated an EF designated *ZzEF*8 which was identified as *F. oxysporum* (Keerthi, D. *et al.* 2016) and characterized as producing the metabolite Umbelliferone (UMB) (Keerthi, D. *et al.* 2023).

SM production by endophytic *Fusarium* spp. have relied on use of potato dextrose (PD) broth or PD agar as commonly used medium (Wongjiratthiti, A. *et al.* 2017). Nutritionally rich agro-residues serves as good alternative culture medium for metabolite production that can reduce the expenses by 30-75% of the total production cost (Panesar R *et al.* 2015; Sadh, P.K. *et al.* 2018). Several studies have reported the use of various agro residues for production of microbial metabolites (Asagbra, A.E. *et al.* 2005; Ezejiofor, T.I.N. *et al.* 2012; Sukan, A. *et al.* 2014; Saravanan, V. and Vijayakumar, S. 2014). With culture media significantly influencing growth and metabolite production, present study was thus undertaken to determine the effectiveness of agro-residues in enhancing growth and metabolite production by the UMB producing endophyte *ZzEF*8 (Keerthi, D. *et al.* 2023).

MATERIALS AND METHODS

Biochemical assay of agro-residues

The agro-residues used in present study were procured from local mills and supermarkets. Selected agro-residues (rice bran, wheat bran, soyabean meal and potato peel) were quantitated for various biochemical parameters like reducing sugar by 3,5-dinitrosalicylic acid (DNSA) method, total sugar by phenol sulphuric acid method (Kurzyna-Szklarek, M. *et al.* 2022) and protein content by Lowry's method (Lowry, O.H. *et al.* 1951). For sample analysis, each of the agro-residue (0.2 g) was suspended in 20 ml of 1.5% (w/v) NaOH separately prior to autoclaving at 121°C for 15 min.

Fungal culture and growth conditions

*ZzEF*8 isolated in earlier studies from *Zingiber zerumbet* (L) Smith (Keerthi, D. *et al.* 2016) and maintained on potato dextrose agar (PDA) slants were used for present study. From the stock cultures, *ZzEF*8 was sub-cultured on PDA plates (pH 6.5) and incubated at 25 ± 3°C for 7 days in dark. Efficiency of agro-residue to be utilized as growth medium by *ZzEF*8 was determined by comparing the values with those determined in PDB media that has been optimized in earlier studies for growth and metabolite production (Saravanan, V. and Vijayakumar, S. 2014).

Effect of various agro-residues on growth and metabolite production

Effect of agro-residues on growth and metabolite production by *ZzEF*8 was studied by one-factor-at-a-time method. For this, *ZzEF*8 hyphal discs from the actively growing edges of seven-day old culture were inoculated into 50 ml basal media (g/L) [$MgSO_4.7H_2O$ 0.6; NH_2SO_4, 1.4; $CaCl_2.2H_2O$, 0.4; KH_2PO_4, 1.6; urea,0.2; yeast extract, 0.2; peptone 0.25] with agro-residues (rice bran, potato peel powder, soyabean meal, wheat bran (1 g/L) and mineral salt solution [$ZnSO_4.7H_2O$, 3.34; $MnSO_4.7H_2O$, 4.6; $FeSO_4.7H_2O$, 3 mg/L (pH 7.0)]. Control comprised of PDB inoculated with *ZzEF*8 hyphal discs from the actively growing edges of seven-day old culture. Cultures were incubated at 25 ± 3°C for 11 days. Following completion of incubation period, broth and mycelia were separated using Whatman No.1 filter paper and the mycelial mat was washed with distilled water, moisture removed and fresh weight recorded. Mycelial dry weight was recorded after drying in hot air oven at 50°C for 2 hours.

UMB production in *ZzEF*8 culture grown in various agro-residues was determined in both culture broth and mycelia. For the same, the cultures incubated for 11 days were filtrated and centrifuged for 15 min at 4000 rpm at 4°C. Mycelia was cold macerated with dichloromethane (DCM, 5 ml/g) and incubated overnight at 100 rpm at 25°C. Organic phase was collected after centrifugation at 8000 rpm for 15 min and evaporated to dryness at 42°C. Both the supernatant from culture broth and mycelial DCM extract was evaluated for UMB content which was recorded as absorbance units (AU) by spectrophotometric determination over a wavelength range of 190-400 nm (T60 UV-Vis Spectrophotometer, PG Instruments Ltd. UK) as reported in earlier studies (Keerthi, D. *et al.* 2023).

RESULTS AND DISCUSSION

Biochemical parameters of agro-residues: Estimation of reducing sugar, total carbohydrate and protein

Agro-residues serve as natural raw materials that are rich in nutrients like carbohydrates, proteins, minerals and vitamins thereby constituting potential culture medium for fungal EFs due to their low cost (Lopes, F.C. and Ligabue-Braun, R. 2021). Majority of studies using agro-residues as substrates have been carried out in fungi wherein wheat bran, rice bran and soybean meal have been identified as promising energy sources promoting growth and SM production (Arumugam, G.K. *et al.* 2014). Moreover, present study selected various agro-residues like rice bran, wheat bran, soyabean meal, potato meal based on the fact that *Fusarium oxysporum* isolates display broad host range and have been identified both as EFs from several plant taxa (Ahmed, A.M. *et al.* 2023) as well as phytopathogen infecting diverse crop plants (Michielse, C.B. and Rep, M. 2009). Considering the high variability in nutrient composition of agro-residues, biochemical evaluation was undertaken. Based on the reducing sugar content, the various agro-residues can be arranged in descending order as PDB > Rice bran > Wheat bran > Potato peel > Soya bean meal. Estimation of total carbohydrate content arranged the agro-residues in ascending order as Soya bean meal < Rice bran < Potato peel < Wheat bran < PDB. Total protein present in the agroresidues were determined using BSA as standard. Based on the protein content, the agroresidues were arranged in ascending order as PDB < wheat bran < Potato peel < Rice bran <Soyabean meal. Results thus reveal higher reducing sugar (975±15 mg/ 100 ml media) and total carbohydrate content in PDB (870±1.3 mg/ 100 ml media) compared to the agro-residues tested in present study. However it had the lower protein content (52.04 ± 0.68 mg/ 100 ml media) compared to soybean meal (98.7 mg/ 100 ml media).

*ZzEF*8 growth and MB production in different culture media

Alterations to the culture media are known to influence not just microbial growth but SM production as well (Miao, L. *et al.* 2006; Antipova, T.V. *et al.* 2015). Despite the classical one-variable at a time (OVAT) process optimization method being time-consuming, the approach is still followed and relevant for optimizing fermentation media of potential endophytes (Singh, V. *et al.* 2017). Earlier studies had optimized fermentation conditions for UMB production by *ZzEF*8 using PDA (Keerthi, D. *et al.* 2023). Present experiments compared UMB production by *ZzEF*8 cultures under the earlier optimized liquid state fermentation conditions in PDB with that obtained in agro-residue based media. *ZzEF*8 hyphal growth was observed in all of the agro-residue based media as determined based on evaluation of fresh weight and dry weight of the harvested mycelia (Fig. 1). Higher mycelial growth was observed on soya bean meal and PDB (Fig. 1 a and e) compared to other agro-residues (Fig. 1 b-d). Further visual inspections showed higher thickness of mycelial mat and pigmentation in PDB, compared to other media evaluated (Fig. 1 a-e).

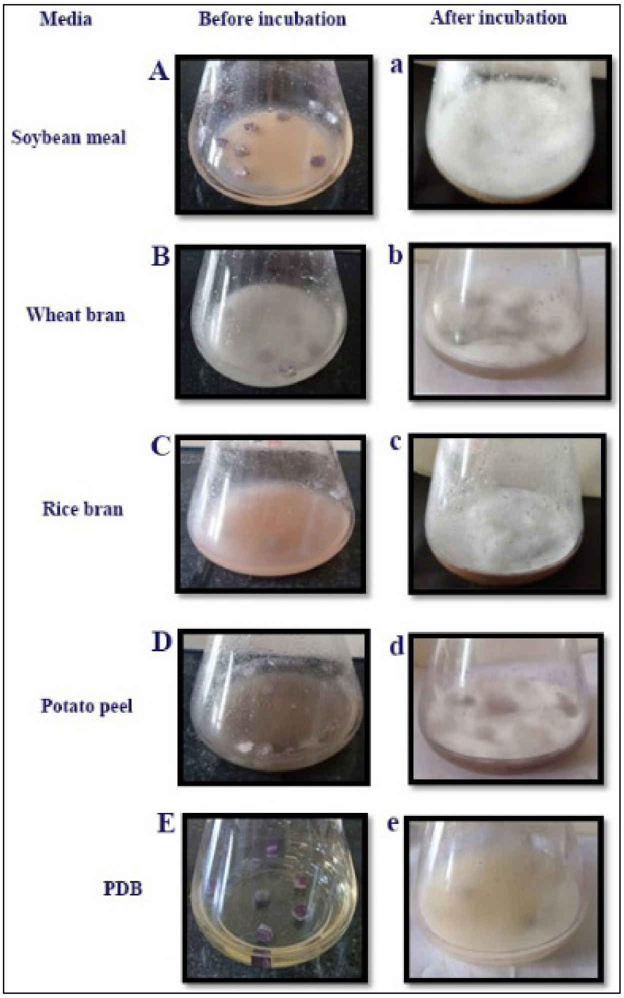


Fig. 1: Growth morphology of *ZzEF8* in different media, **A-E**: Before incubation. **a-e:** after incubation period of 11 days

Though in soya bean meal media the mycelial thickness was comparable to PDB, lower pigmentation was observed compared to PDB. Evaluation of *ZzEF*8 biomass (wet weight and dry-weight) revealed higher values corresponding to fresh weight (2.08 ± 0.49 g) and dry weight (0.214±0.06 g) of *ZzEF*8 in PDB media followed by soybean meal media (Fig. 2). Low biomass was observed in media based on rice bran, wheat bran and potato peel (Fig. 2). Significant difference in biomass (wet weight) was observed in PDB compared to wheat bran ($p \leq 0.001$) and rice bran ($p \leq 0.01$) (Fig. 2).

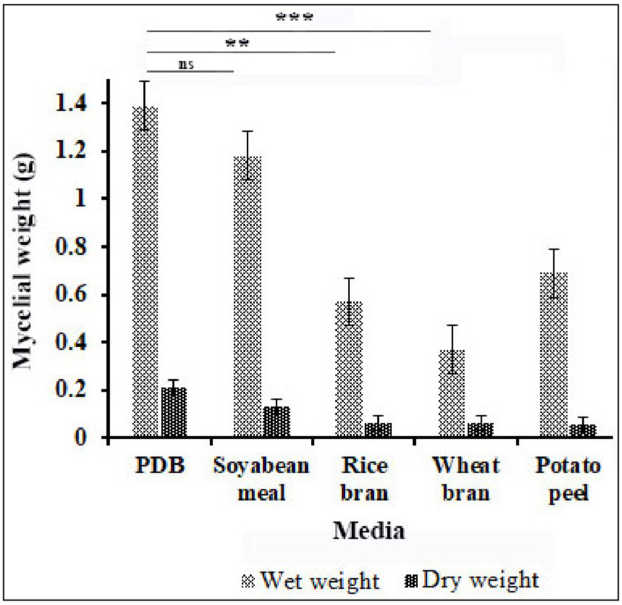


Fig. 2: Growth profile (wet weight and dry weight) of *ZzEF*8 in different media. The data represents mean ± SEM values from triplicate samples for each group, and the significance are shown as p≤0.001: ***; p≤0.001: ** and ns: not significant

The differential growth of *ZzEF*8 in various agro-residues can be accounted to the inhibitory effect of various agro-residues on microbial growth (Gomes-Araújo, R. *et al.* 2021). Moreover, various studies have cited growth suppression of pathogenic *Fusarium* spp in soil amended with plant residues or agro-residues such as suppression of *Fusarium* wilt in banana by pineapple residue amendment (Yang, J. *et al.* 2023) and inhibition of *F. oxysporum* growth in melon, tomato and cucumber following amendment with plant residue-based compost (Yogev, A. *et al.* 2006).

UMB production was evaluated in *ZzEF*8 grown in the selected agro-residue based media. A peak at wavelength ranging from 196 -212 nm was found common to all the samples (Supplementary Fig. 1). In mycelial extract, peak at wavelength ranging from 240 -275 nm was found common to all the samples (Supplementary Fig. 1a-e). Earlier studies had characterized the *ZzEF*8 metabolites in PDB

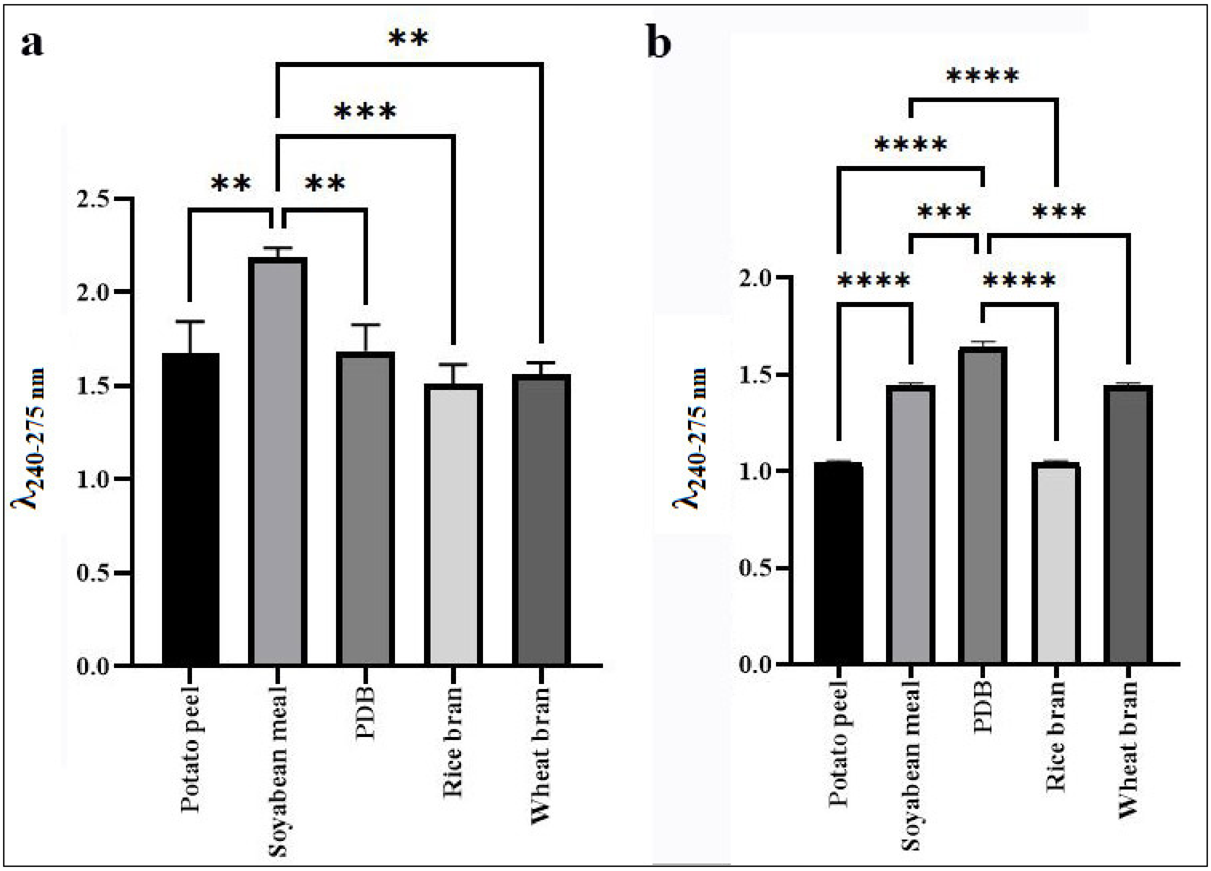
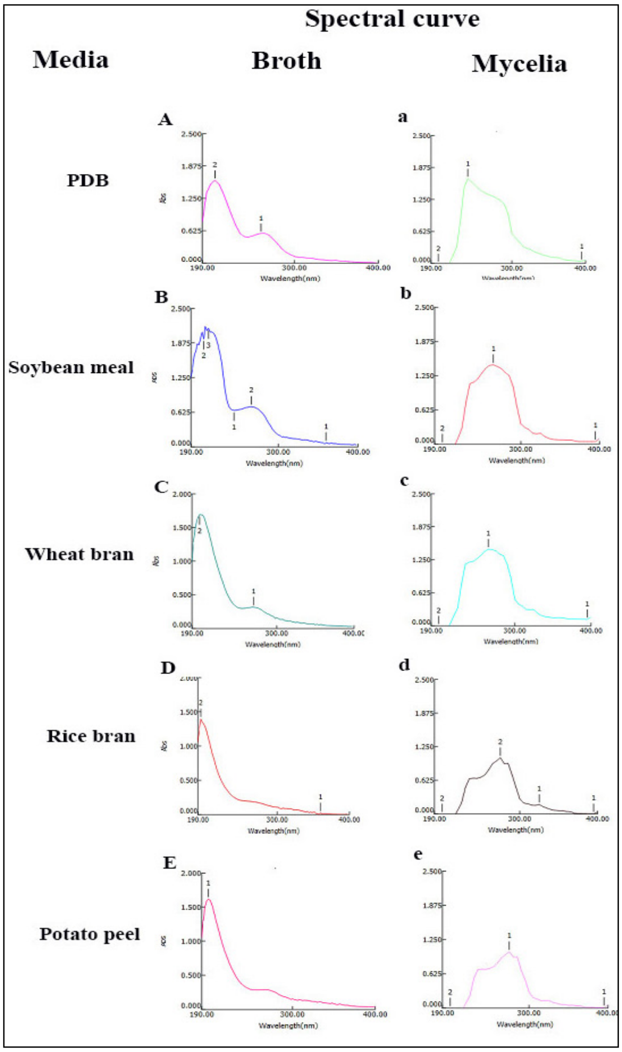


Fig. 3: Metabolite absorbance profile of *ZzEF*8 (190-400 nm) extract prepared from **a**) broth and **b**) mycelia grown in different media. The data represents mean ± SEM values from triplicated samples for each group with significance at p >0.002 shown as '**', p >0.0002 as '*** and p<0.0001 shown as '****'

medium and identified this peak to correspond to UMB (Keerthi, D. *et al.* 2023). Evaluation of metabolite content in broth showed significantly higher UMB content in soyabean meal media (2.18 ± 0.05 AU) compared to PDB (1.68 ± 0.14 AU) and potato peel media (1.67 ± 0.16 AU) (p>0.002) (Fig. 3a). In the mycelial extract, significantly higher UMB content was observed in PDB (1.64 ± 0.02 AU) compared to soya bean meal media (1.44 ± 0.01 AU) and wheat bran (1.44 ± 0.01 AU) (p>0.0002) (Fig. 3b). No additional peaks were detected amongst the media supplemented with various agro-residues but lower peak intensity was observed in rice and wheat bran based media. Higher content of recalcitrant components such as lignocellulose, hemicellulose and lignin in agro-residues like rice and wheat bran could be deterring their utilization for growth by the endophytic *ZzEF*8. Experiments thus reveal PDB as a better medium for *ZzEF*8 UMB production compared to agro-residue based media. These observations corroborate earlier reports wherein PDA was identified as best media supporting EF growth and yielding higher metabolite production such as in *Monascus* spp. for citrinin production (Abdel-Raheam, H.E.F. *et al.* 2022), prodigiosin production by *Serratia marcescens* (Xia, Y. *et al.* 2016) and SM, E2.2 by *Phaleria macrocarpa* (Gasong, B.T. and Tjandrawinata, R.R. 2016). In *Aspergillus fumigatus* strain MF1 (Kalyani, P. *et al.* 2023), *A. terreus* KC 582297 and *Aspergillus* strain TSF 146 (Bhattacharyya, PN and Jha, D.K. 2011; Mathan, S. *et al.* 2013). Present study identified PDB as the best culture medium for yielding higher production of UMB. In *Fusarium* spp., many biosynthetic gene clusters (BGCs) involved in carotenoid pigment production are reported to remain silent under standard laboratory conditions. Such silent BGCs get activated under *in vitro* conditions depending on the nutritional input in media. Present study provides evidence to this aspect as revealed by higher pigment production in PDB medium compared to soybean meal indicative of the requirement of glucose rich sources by *ZzEF*8 for pigment production. Contrarily soybean meal which is rich in nitrogen source (amino acids) despite stimulating mycelial growth did not induce pigment production, presumably due to the non-involvement of amino-acid derived intermediary metabolites in pigment production.



Supplementary Fig. 1: Spectral analysis (180- 400 nm) of secondary metabolites observed in extracts from broth (A- E) and mycelia (a- e) of *ZzEF*8 cultures grown in different media

CONCLUSION

SM production is known to critically depend on cultivation conditions (Antipova, T.V. *et al.* 2015) such that alterations to the culture medium influences not just microbial growth but metabolism as well (Miao, L. *et al.* 2006). Changing nutrient regimes and medium composition thus constitutes one of the simplest strategies to induce the cryptic biosynthetic gene(s) under *in vitro* conditions (Reen, F.J. *et al.* 2015). Culture media based on agro-residues is considered an efficient and profitable way to diminish the cost of production (Sadh, P.K. *et al.* 2018). Though several studies have reported agro-residues as alternate energy sources for fungal growth on large scale, these substrates tend to be highly variable due to the differences in traditional processing techniques that fail to guarantee a standardized product (Sadh, P.K. *et al.* 2018). Therefore, despite being considered expensive and relying on a food crop, PDA which contains potato infusion and dextrose as carbohydrate source constitutes a universal fungal media. Study thus demonstrates PDA as ideal medium for growth of endophytic *ZzEF*8 which supports luxuriant mycelial growth thereby yielding higher UMB from mycelial extract compared to agro-residue based media.

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REFERENCES

Abdel-Raheam, H.E.F., Alrumman, S.A., Gadow, S.I., El-Sayed, M.H., Hikal, D.M., Hesham, A.E. and Ali, M.M.A. 2022. Optimization of *Monascus purpureus* for natural food pigments production on potato wastes and their application in ice lolly. *Frontiers in Microbiology*, **13**: 862080.

Ahmed, A.M., Mahmoud, B.K., Millán-Aguiñaga, N., Abdelmohsen, U.R. and Fouad, M.A. 2023. The endophytic *Fusarium* strains: a treasure trove of natural products. *RSC Advances*, **13**: 1339-1369.

Alam, B., Li, J., Ge, Q., Khan, M.A., Gong, J., Mehmood, S., Yuan, Y. and Gong, W. 2021. Endophytic fungi: from symbiosis to secondary metabolite communications or vice versa? *Frontiers in Plant Science*, **12**: 1-24.

Antipova, T.V., Zhelifonova, V.P. and Kozlovsky, A.G. 2015. Effect of cultivation conditions on production of secondary metabolites by *Penicillium citrinum*. *Microbiology*, **84**: 365–369.

Arumugam, G.K., Selvaraj, V., Gopal, D. and Ramalingam, K. 2014. Solid-state fermentation of agricultural residues for the production of antibiotics. *In:* Brar S, Dhillon G, Soccol C (eds) Biotransformation of waste biomass into high value biochemicals. Springer, pp. 139- 162.

Asagbra, A.E., Sani, A.I. and Oyewole, O.B. 2005. Solid state fermentation production of tetracycline by *Streptomyces* strains using some agricultural wastes as substrate. *World Journal of Microbiology and Biotechnology*, **21**: 107–114.

Bao, J., Fravel, D., Lazarovits, G., Chellemi, D., van Berkum,

P. and O'Neill, N. 2004. Biocontrol genotypes of *Fusarium oxysporum* from tomato fields in Florida. *Phytoparasitica,* **32**(1): 9–20.

Bhattacharyya, P.N. and Jha, D.K. 2011. Optimization of cultural conditions affecting growth and improved bioactive metabolite production by a subsurface *Aspergillus* strain TSF 146. *International Journal of Applied Biology and Pharmaceutical technology,* **2**(4): 133-145.

Bills, G.F. and Gloer, J.B. 2016. Biologically active secondary metabolites from the fungi. *Microbiol Spectrum,* **4**(6).

Cui, R., Lu, X., Chen, X., Malik, W.A., Wang, D., Wang, J., Wang, S., Guo, L., Chen, C., Wang, X., Wang, X., Dai, M. and Ye, W. 2021. A novel raffinose biological pathway is observed by symbionts of cotton *Verticillium dahliae* to improve salt tolerance genetically on cotton. *Journal of Agronomy and Crop Science,* **207**: 956–969.

da Rosa-Garzon, N.G., Laure, H.J., Rosa, J.C. and Cabral, H. 2019. *Fusarium oxysporum* cultured with complex nitrogen sources can degrade agricultural residues: Evidence from analysis of secreted enzymes and intracellular proteome. *Renewable Energy,* **133**: 941-950.

Ezejiofor, T.I.N., Duru, C.I., Asagbra, A.E., Ezejiofor, A.N., Orisakwe, O.E., Afonne, J.O. and Obi, E. 2012. Waste to wealth: production of oxytetracycline using *Streptomyces* species from household kitchen wastes of agricultural produce. *African Journal of Biotechnology,* **11**: 10115–10124.

Fisher, M.C., Henk, D.A., Briggs, C.J., Brownstein, J.S., Madoff, L.C., McCraw, S.L. and Gurr, S.J. 2012. Emerging fungal threats to animal, plant and ecosystem health. *Nature,* **484**(7393): 186–194.

García-Bastidas, F., Ordóñez, N., Konkol, J., Al-Qasim, M., Naser, Z., Abdelwali, M., Salem, N., Waalwijk, C., Ploetz, R.C. and Kema, G.H.J. 2014. First report of *Fusarium oxysporum* f. sp. cubense tropical race 4 associated with Panama disease of banana outside Southeast Asia. *Plant Disease,* **98**(5): 694.

Gasong, B.T. and Tjandrawinata, R.R. 2016. Production of secondary metabolite E2.2 from *Phaleria macrocarpa* endophytic fungus. *Asian Pacific Journal of Tropical Biomedicine,* **6**: 881-885.

Gomes-Araújo, R., Martínez-Vázquez, D.G., Charles-Rodríguez, A.V., Rangel-Ortega, S. and Robledo-Olivo, A. 2021. Bioactive compounds from agricultural residues, their obtaining techniques, and the antimicrobial effect as post-harvest additives. *International Journal of Food Science,* **17**: 9936722.

Guevara-Araya, M.J., Vilo, C., Urzúa, A. and González-Teuber, M. 2020. Differences in community composition of endophytic fungi between above- and below-ground tissues of *Aristolochia chilensis* in an arid ecosystem. *Revista Chilena de Historia Natural,* **93**: 3.

Hiruma, K., Gerlach, N., Sacristan, S., Nakano, R.T., Hacquard, S., Kracher, B., Neumann, U., Ramírez, D., Bucher, M., O'Connell, R.J. and Schulze-Lefert, P. 2016. Root endophyte Colletotrichum tofieldiae confers plant fitness benefits that are phosphate status dependent. *Cell,* **165**: 464–474.

Imazaki, I. and Kadota, I. 2015. Molecular phylogeny and diversity of *Fusarium* endophytes isolated from tomato stems. *FEMS Microbiology and Ecology,* **91**: fiv098.

Jumpponen, A. and Jones, K.L. 2009. Massively parallel 454 sequencing indicates hyperdiverse fungal communities in temperate *Quercus macrocarpa* phyllosphere. *New Phytology,* **184**: 438– 448.

Kalyani, P., Botsa, S.M., Laxmi, K.V.D. and Anil, S. 2023. Optimization of cultural conditions for biomass and antibacterial metabolite production by *Aspergillus fumigatus* strain MF1. *Hybrid Advances,* **2**: 100016.

Kaul, S., Sharma, T. and Dhar, M.K. 2016. "Omics" tools for better understanding the plant-endophyte interactions. *Frontiers in Plant Science,* **7**: 955.

Keerthi, D., Aswati, N.R. and Prasath, D. 2016. Molecular phylogenetics and anti-*Pythium* activity of endophytes from rhizomes of wild ginger congener, *Zingiber zerumbet* Smith. *World Journal of Microbiology and Biotechnology,* **32**: 41.

Keerthi, D., Harsha, K., Harshitha, K. and Aswati, R.N. 2023. Potential of *Zingiber zerumbet* endophytic *Fusarium oxysporum* as biopriming agents to control *Pythium* mediated soft-rot and optimization of fermentation conditions for cytotoxic metabolite(s) production. *Journal of Plant Biochemistry and Biotechnology,* **32**: 163–173.

Kumar, K.K. and Dara, S.K. 2021. Fungal and bacterial endophytes as microbial control agents for plant-parasitic nematodes. *International Journal of Environmental Research and Public Health,* **18**(8): 4269.

Kurzyna-Szklarek, M., Cybulska, J. and Zdunek, A. 2022. Analysis of the chemical composition of natural carbohydrates - An overview of methods. *Food Chemistry,* **394**: 133466.

Lopes, F.C. and Ligabue-Braun, R. 2021. Agro-industrial residues: Eco-friendly and inexpensive substrates for microbial pigments production. *Frontiers in Sustainable Food Systems,* **5**: 589414.

Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. 1951. Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry,* **193**(1): 265-275.

Mathan, S., Subramanian, V. and Nagamony, S. 2013. Optimization and antimicrobial metabolite production from endophytic fungi *Aspergillus terreus* KC 582297. *European Journal of Experimental Biology,* **3**(4): 138-144.

Miao, L., Kwong, T.F.. and Qian, P.Y. 2006. Effect of culture conditions on mycelial growth, antibacterial activity and metabolite profiles of the marine-derived fungus *Arthrinium* c.f. *saccharicola*. *Applied Microbiology and Biotechnology,* **272**(5): 1063- 1073.

Michielse, C.B. and Rep, M. 2009. Pathogen profile update: *Fusarium oxysporum*. *Molecular Plant Pathology,* **10**(3): 311-324

Naik, B.S., Shashikala, J. and Krishnamurthy, Y.L. 2009. Study on the diversity of endophytic communities from rice (*Oryza sativa* L.) and their antagonistic activities *in vitro*.

Microbiology Research, **164**: 290–296.

Panesar, R., Kaur, S. and Panesar, P.S. 2015. Production of microbial pigments utilizing agro-industrial waste: a review. *Current Opinion in Food Science*, **1**: 70–76.

Poveda, J. and Baptista, P. 2020. Filamentous fungi as biocontrol agents in olive (*Olea europaea* L.) diseases: Mycorrhizal and endophytic fungi. *Crop protection*, **146**: 105672.

Poveda, J., Eugui, D., Abril-Urías, P. and Velasco, P. 2021. Endophytic fungi as direct plant growth promoters for sustainable agricultural production. *Symbiosis*, **85**: 1–19.

Qin, S., Xing, K., Jiang, J.H., Xu, L.H. and Li, W.J. 2011. Biodiversity, bioactive natural products and biotechnological potential of plant-associated endophytic actinobacteria. *Applied Microbiology and Biotechnology*, **89**(3): 457–473.

Qu, B., Li, H.P., Zhang, J.B., Xu, Y.B., Huang, T., Wu, A.B., Zhao, C.S., Carter, J., Nicholson, P. and Liao, Y.C. 2008. Geographic distribution and genetic diversity of *Fusarium graminearum* and *F. asiaticum* on wheat spikes throughout China. *Plant Pathology*, **57**(1): 15-24.

Radic, N. and Strukelj, B. 2012. Endophytic fungi: the treasure chest of antibacterial substances. *Phytomedicine*, **19**: 1270–1284.

Reen, F.J., Romano, S., Dobson, A.D.O. and Gara, F. 2015. The sound of silence: activating silent biosynthetic gene clusters in marine microorganisms. *Marine Drugs*, **13**(8): 4754-83

Sadh, P.K., Duhan, S. and Duhan, J.S. 2018. Agro-industrial wastes and their utilization using solid state fermentation: a review. *Bioresources and Bioprocessing*, **5**: 1.

Saravanan, V. and Vijayakumar, S. 2014. Production of biosurfactant by *Pseudomonas aeruginosa* PB3A using agro-industrial wastes as a carbon source. *Malaysian Journal of Microbiology*, **10**(1): 57–62.

Singh, V., Haque, S., Niwas, R., Srivastava, A., Pasupuleti, M. and Tripathi, C.K. 2017. Strategies for fermentation medium optimization: an in-depth review. *Frontiers in Microbiology*, **27**: 2087.

Stępień, Ł., Lalak-Kańczugowska, J., Witaszak, N. and Urbaniak, M. 2018. *Fusarium* secondary metabolism biosynthetic pathways: so close but so far away. *In:* Merillon, JM., Ramawat, K. (eds) Co-Evolution of Secondary Metabolites. Reference Series in Phytochemistry. Springer, pp. 1–37.

Strobel, G. and Daisy, B. 2003. Bioprospecting for microbial endophytes and their natural products. *Microbiology and Molecular Biology Reviews*, **67**(4): 491-502.

Strobel, G. 2018. The emergence of endophytic microbes and their biological promise. *Journal of Fungi (Basel)*, **4**(2): 57.

Sukan, A., Roy, I. and Keshavarz, T. 2014. Agro-industrial waste materials as substrates for the production of poly (3-hydroxybutyric acid). *Journal of Biomaterials and Nanobiotechnology*, **5**: 229–240.

Summerell, B.A. and Leslie, J.F. 2011. Fifty years of *Fusarium*: how could nine species have ever been enough? *Fungal Diversity*, **50**: 135–144.

Toghueo, R.M.K. 2019. Bioprospecting endophytic fungi from *Fusarium* genus as sources of bioactive metabolites. *Mycology*, **11**(1): 1-21.

Uzma, F., Mohan, C.D., Hashem, A., Konappa, N.M., Rangappa, S. and Kamath, P.V. 2018. Endophytic fungi-alternative sources of cytotoxic compounds: a review. *Frontiers in Pharmacology*, **9**: 309.

Wongjiratthiti, A., Nakhon, S. and Yottakot, S. 2017. Utilisation of local crops as alternative media for fungal growth. *Journal of Tropical Agricultural Science*, **40**(2): 295-304.

Xia, Y., Wang, G., Lin, X., Song, X. and Ai, L. 2016. Solid-state fermentation with *Serratia marcescens* Xd-1 enhanced production of prodigiosin by using bagasse as an inertia matrix. *Annual Microbiology*, **66**: 1239–1247.

Xing, X. and Guo, S. 2011. Fungal endophyte communities in four Rhizophoraceae mangrove species on the south coast of China. *Ecological Research*, **26**(2): 403–409.

Yang, J., Wu, Q., Wang, Y., Chen, X., Gao, W., Zhao, Y., Wang, B.. and Ruan, Y. 2023. Suppression of banana *Fusarium* wilt disease with soil microbial mechanisms via pineapple rotation and residue amendment. *Agronomy*, **13**: 377.

Yogev, A., Raviv, M., Hadar, Y., Cohen, R. and Katan, J. 2006. Plant waste-based composts suppressive to diseases caused by pathogenic *Fusarium oxysporum*. *European Journal of Plant Pathology*, **116**: 267–278.

Yuan, Z.L., Zhang, C.L., Lin, F.C. and Kubaik, C.P. 2010. Identity, diversity and molecular phylogeny of the endophytic mycobiota in the roots of rare wild rice (*Oryza granulata*) from nature reserve in Yunnan, China. *Applied and Environmental Microbiology*, **76**(5): 1452–1652.

Zakaria, L. and Ning, C.H. 2013. Endophytic *Fusarium* spp. from roots of lawn grass (*Axonopus compressus*). *Tropical Life Science Research*, **24**(2): 85-90.